

Science Centres	Average annual visitors (millions)
Science Museum, London	1.7
Cite de Sciences, Paris	3.5
Air & Space Museum, Washington DC	7.0
Science City, Kolkata	1.5
Global total	350.0 (approx)

Table 1: Major Science Museums/Centres and their average annual visitor figure.

### Scientific Awareness & Scientific Temper

Having understood the vital role of science centres in public education, we can well guess that they can play a very important role in creating a scientific awareness in the society, developing a scientific temper among the people, elicit public opinion on controversial scientific issues, dispel social taboos and superstitions and thus indirectly play the role of social reformers of the modern society. In India, science centres rendered a yeoman service in dispelling widespread superstition about celestial events or diseases. The science centres also provide a platform for social interactions on scientific issues that, and encourages and facilitates better learning of science. *Cameron*<sup>29</sup> argues, cultural institutions can act as the trusted incubators for change by providing a variety of information sources, offering challenging and participatory experiences but significantly for science centres to facilitate visitors to engage topics on their own terms in their own capacity as expert informants as opposed to the older pedagogic paradigm as authority. In addition to the evidence of the gain of knowledge and understanding, considerable evidence has also been collected of visitors to science centres practicing and developing skills of exploration, observation, interpreting data, sharing ideas, and other skills directly related to scientific belief (e.g. *Allen*<sup>31</sup>; *Borun, Chambers, & Cleghorn*<sup>32</sup>; *Tunncliffe, Lucas, & Osborne*<sup>33</sup>; *Schauble et al.*<sup>34</sup>; *Crowley et al.*<sup>35</sup>; *Crowley & Jacobs*<sup>36</sup>).

### Community Partnerships

Scholars and users argued that a deeper relationship between the science centre and its public is necessary in order to sustain the institutional renewal process. A science centre is not defined merely by its display but rather by how its resources are used to achieve the goals framed by its mission and by the interactions developed with its public<sup>37</sup>. It is, therefore, necessary to develop partnership with the surrounding community including schools, colleges, universities, research labs, various societies and NGOs and encourage them to collaborate with the science centres. This enhances the effectiveness of as well as public support for the science centres. The activities of

policies of science centres directed to community have positive impact in establishing such partnership as evidenced by the participation and utilization of science centre resources.

### Science Centers as Resource Centres

The science centres develop a joint venture with other organizations, including schools, to bring the science center hands-on curriculum with variety of props into the classroom or to organize several innovative educational programs, thus act a facilitator of science and technology transfer; for example, for the production of educational kits. The centers also endeavor as a catalyst for the conveyance of innovation from research to new business activities. The institution develops into a resource for science education, vocational guidance and providing training; for example, experiences of student both at the science centre and in the classroom, teacher development programs and materials resources, distance learning opportunities, interactive events and virtual exhibits on the internet. Several science museums use their collections in combination with hands-on exhibitions and innovative programs to support inquiry-based learning (such as the Science Museum and the Natural History Museum in London, and the Deutsches Museum in Munich). *Kelly*<sup>38</sup> examined the roles of (science) museums as credible information resource for an increasingly complex contemporary information society and in the contentious subjects' context. In India, developing learning resources including exhibits as per the need of the educational institutions and by organizing in a way that supplement school curriculum have made science centres as important institutions to fall back for education system. *Bradburne*<sup>39</sup> recommends that Science Centres should become collection (including hands on exhibits) and user oriented rather than collection and visitor oriented.

### A Source of Pride for the Local Community

The science centres focus for generating pride in their region for local residents, resulting from the success and reputation of the science centre. According to *Rosentraub*<sup>40</sup> the visitors see The Children's Museum as the core factor in the cultural identity of Indianapolis and Central Indiana and the residents include it among reasons for pride towards living in the area. He also suggested that "The reputation ... and the pride produced for an area's residents by a civic asset can be as important or in some instances more robust than the economic benefits." The fame of the local community is also improved by the display, in several other parts of the country, of the museum's name on its travelling exhibits. Local community takes pride in facilitating or recommending visit to science centres for their guests and relatives or accompanies them which enhance social interaction

and values. In India Science City, Kolkata has become an iconic place of pride both for local community and government.

## Environmental Restoration

Science Centres are often built on plots which would have no other utility. However, once the science centres are built and lush greenery of science parks develop, an environmental restoration and upgradation takes place. Two glaring examples from India are Nehru Science Centre, Mumbai and Science City, Kolkata which were built on garbage dumping grounds.

## Economic Impact

A study by Groves<sup>41</sup> has dealt the economic impact in detail. Economic impact is made up of primary and secondary impacts: primary or direct economic impact is referred as the expenditure by the science centre itself, in addition to the expenditure by those visitors to the science centre who come from outside the local region in order to visit the centre helping to increase economic activity. Secondary economic impact is a combination of indirect and induced impacts. Indirect economic impact refers to the fact that expenditure by the science centre and its visitors contribute new money into the economy by inducing the purchasing of goods and services in order to satisfy the requirements of the science centre and its visitors. Hence are named as the 'supplier' effects. Induced economic impact is the flow-on created by the collective effect of direct and indirect economic impacts. Larger total wages and increased organizational revenues are, partially, returned to the local economy through further 'consumption' expenditure.

Indirect and induced impacts can only be quantified on the basis of a good understanding of the overall economy and inter-industry relationships in the region concerned. Fiscal impact on the local (or wider) economy also results from an institution's activities. This is related to but separate from the economic impact. An institution's direct economic impact occurs as a result of its own spending and spending by some of its out-of-region visitors. It also includes the jobs provided directly by the institution. The direct impact resulting from the institution's own spending, on both employee wages and payments to suppliers of goods and services, is readily determined from the institution's salary and expenditure records. Brand *et al.*<sup>42</sup> and Witschey<sup>43</sup> recommended a broader foundation for considering 'economic impact', although the secondary impacts are hard to be quantified.

## Local/regional/international Tourism

The science centres provide a source of attraction especially for tourists, both local/regional and

international in its own right. It also develops a partnership with local hotels in packaging tourism offers. The centres often develop a partnership with tour operators, to link up with other attractions in the region. Persson<sup>2,44</sup> has indicated that 30 percent of US population pays at least one visit to science centres annually. The figure is 16 percent for Great Britain, 10 percent for Scandinavian countries and about 1 percent for India. Globally science centres draw about 350 million visitors every year. This is about 6 percent of the global population. Jasper<sup>45</sup> reported that "the business survey calculated the positive and negative influences on local tourism-related businesses, increments as well as reductions in the customer number and income; along with the improvements and a positive effect on the image of a worsening of traffic in some areas and some increased difficulties of recruitment. However, the positive effects were, overall, stronger than the negative ones, and arguably the most significant effect was a lengthening of the tourist season."

## Income Brought into the Science Center from Visitors

Ninety percent of the science centres in the world charge entry fee to their visitors. By the year 2000, the total turnover of science centres around the world was US\$1.4 billion. One can assume an increase of 30 percent over last ten years making it to about US\$2.0 billion. Beetlestone *et al.*<sup>1</sup>, Persson<sup>2,4</sup> Groves<sup>41</sup> reported that Science Centres in the USA generate 80-90 percent of their operating expenditure from various sources of income. The figure is 60-70 percent for children's museums in the USA, 15-20 percent for science centres in the UK, 30-70 percent for other ECSITE members and 46 percent of the operating cost for NCSM (except Science City, Kolkata which is self reliant). Globally, the figure is about 45 percent<sup>41</sup>. Thus, we see that visitors contribute a huge sum of income to the science centres. Wright<sup>46</sup> concluded from his studies that while the science centres "will never become self-sustaining, a larger facility would allow for more earned income, near or at 60 percent of annual cost of services (compared with the current 50 percent), in addition to an added annual economic impact of over \$500,000".

## Income Brought into Community by Visitors

The science centres act as a cause of income for a group of community associated with providing travel, food, accommodation, retail purchases and visits to other attractions for visitors. The institutions provide flow-on effects to other businesses and industries in the region—the extra turnover generated for suppliers and the resulting growth in employment and local spending power, and successive waves of such impacts among

downstream suppliers and service providers. These flow-on effects are sometimes called multiplier effects. *Greene*<sup>47</sup> observed, "For every pound sterling spent by visitors at the museum (The Museum of Science and Industry in Manchester), twelve pounds are spent elsewhere in the local economy."

### Science Center Expenditure

Globally science centres have an operating budget of more than US\$4 billion annually. Surveys showed that about 55 percent of this goes for Non Plan expenditure including staff salary. Remaining 45 percent is developmental expenditure which primarily contributes to national and local economy, which in turn generates employment. Science Centres also pay various taxes and revenues to government and local bodies.

### Contributing to Urban Development

The science centres promote site rehabilitation by encouraging governmental or municipal funding to the region, for the redevelopment of the areas near the science centers site. New roads are built, new transport links are established. Small scale urbanization takes place around every science centre. As considerable land is required to set up a science centre and land is scarce in cities, in most cases it happens that unwanted land gets allotted for the development of science centre. The science centre in such land enhances the value and contributes to development of the area. In three such examples, the Nehru Science Centre, Mumbai, Raman Science Centre, Nagpur and Science City, Kolkata were set up on erstwhile garbage dumping grounds of respective cities. Now these localities have been transformed into prime and valuable localities.

### Appreciation of Real Estate

The development of the areas close to the science centres gets an economic upward thrust owing to the overall upgradation in property of the local areas and thus the economic development of the local property owners. Housing investment activities of community development corporations can be associated with a positive impact on the residential real estate market within their respective service. A striking example is the Science City, Kolkata where the land cost appreciated over four hundred times in 15 years after its development in hitherto garbage dumping ground.

### Direct and Indirect Job Creation

The science centres act as a source of opportunities for local businesses in order to promote their products and services through association with the

same. They provide employment opportunities, particularly for students and the youth group of the society, including internships, vocational training, job guidance and start-up projects. They sometimes endow with travelling exhibitions and outreach programs to other venues or to other communities,



Fig. 6. Science Centre's social responsibility: Vocational training for rural women.

generating income for those as well. Science Centres under NCSM, particularly the small centres situated in remote and backward areas, have a long tradition of providing vocational training to the local unemployed people, which could help them start small enterprises and earn a decent living. In many such cases in India, the Science Centres acted as catalysts of technology transfer from laboratories and industries to the local community.

### Political Impact

The political impact refers to the system in which the policy-makers and policies are affected by the learning, knowledge or value of social development attached. The influence is administered by the interests and attitudes of the politicians, administrations and citizens while having a query about the public interest involving science and technology, public action like law-jurisprudence-ethics, politics, including several events on regulating norms, standard rules and the participation of the citizens in making scientific and technological decisions. *Lafrance*<sup>48</sup> noted, "The Laurentian University faculty behind the new Graduate Diploma in Science Communication believe that citizens need to get a handle on the quickly-evolving information to be in a position to weigh risks, make choices and question the decisions of policy makers and politicians. Only then can they fully participate in the affairs of their communities and countries." The science centres, as described by *Ferguson*<sup>49</sup> as "powerful symbols and signifiers of political identity...act as a moral technology for many", have played a vital role in stimulating the knowledge of the citizens to come across the contentious subjects making an auspicious embankment towards the political knowledge of the citizens. *Cameron*<sup>29</sup> also suggested, "the institutions might consider re-politicizing practice", that is, to leave the monotonous prevailing

methods of pedagogy and to allow the public to look into the scenario in a more open-minded, precise manner in order to generate expertise group of general public who can deliver their knowledge, potentials and skills to the ordinary in a much more easily understandable way to capture the ordinaries' minds rapidly and deeply.



Fig. 7. For leaders of the country, science centres are important for overall development

In India, the connotation of political impact is different. Since the independence of India in 1947, the government has been considering the science museums and centres as an integral part of the overall development (educational as well as socio cultural) of the country. In 1978, NCSM was formed as the apex body of all science museums and science centres with a goal of setting up of science centres at every nook and corner of the country. After thirty two years of existence NCSM has 27 units under its control. The Council has developed eleven more centers for various state governments and other institutions and nine more are under development. Twenty five new projects specially from states are under consideration. In addition, NCSM has provided catalytic support to many Science Centres in India and abroad. Very often proposals are received for new science centres from leaders who consider science centres as tool of constituency development. This shows that the policymakers at governmental level consider science centres as an important tool for societal development.

## Conclusion

Qualitatively it is easy to understand the impact of science centres on different aspects of our lives. However, most studies conducted are focused on short term impact. The real challenge is how to measure and demonstrate the long-term impacts on individuals and communities. Also, most of the studies concentrated on Personal Impact. There are very few studies on societal or economic impact and practically no study on political impact. A systematic study of long term impacts, personal, social, economic and political would reveal, quantitatively, the real benefits of science centres.

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## Obituary



Samir Kumar Ray, Director of the Central Research & Training Laboratory under the National Council of Science Museums (NCSM) passed away suddenly on January 02, 2010 following a cardiac arrest. He was 57 and was survived by two young sons. Ray's wife had expired a month prior to his untimely demise, the rude shock of the great loss that badly effected his health. A Mechanical Engineer by profession, S. K. Ray joined the National Council of Science Museums in 1979. Throughout his career he was involved in different exhibit development projects at District Science Centres at Purulia and Dharampur, National Science Centre, Delhi and Visvesvaraya Industrial & Technological Museum, Bangalore, to name a few. Known for his honest and punctual personality, S. K. Ray left indelible marks in the areas of exhibition design and fabrication. In the year 1998, he took charge of the R&D hub of the National Council of Science Museums, the Central Research & Training Laboratory (CRTL) in Kolkata. During his tenure as the Director, CRTL, he played a pivotal role in embarking on its first overseas turnkey project of the Rajiv Gandhi Science Centre in the island country of Mauritius. He was instrumental in dealing with a number of overseas ventures of the Council especially in the areas of extending catalytic support in terms of conceptualization, development and installation of interactive science learning exhibits to institutions of excellence in countries like Turkey, Israel, Bangladesh and so on. He endeavoured that the Central

Research & Training Laboratory scaled new heights in designing, developing and applying state-of-the-art technologies in science communication. Designing need-based training modules for science communicators and curators in the changing technological scenario was his other interest in the CRTL. He was also an important member of the core team in launching the two-year full time academic

course, Master of Science (MS) in Science Communication of the Council in collaboration with Birla Institute of Science & Technology (BITS), Pilani. As a part of his responsibilities, S. K. Ray had to undertake a number of overseas assignment-cum-study tours in USA, Germany, erstwhile USSR, Mauritius, Vietnam, Bangkok and Nepal.

An alumni of the Purulia Ramakrishna Mission School in the early days and later on, of the Narendrapur Ramakrishna Mission College, Samir Kumar Ray was adisciplinarian. Endeared to all for his affable nature, his unfortunate demise created a void which is difficult to fill in the Council. The entire staff members of the National Council of Science Museums deeply condole the untimely death of Samir Kumar Ray which has come as a shock to the entire Council and to all who knew him.

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 Director, CRTL

## Presenting Indian Science and Technology Heritage in Science Centres (Part 1)

Shivaprasad Khened

### Abstract

*The Indian Civilization has a long recorded history of scientific culture that goes back to more than 5000 years and with China; India is one of the longest surviving civilizations who have made profound contributions to the growth of science and technology. Yet when it comes to portrayal of India's contribution to science and technology, it is completely neglected or over looked. One finds mainly a Eurocentric perspective in history of science; typically, it starts with Greece, neglecting the influences of others upon Greece and then it fast forwards many centuries to the renaissance period to portray modern science to be the sole contribution of Europe.*

*The objective of developing the gallery "Our Science and Technology Heritage" at the National Science Centre, Delhi was to try and correct the portrayal of Indian civilization and present a true picture of what its contributions is in the field of science and technology. The gallery covering an area of 1100 square meters has adopted a mixture of a typical museum and science centre presentation approach in its presentation. Considering the vastness of the subject and also the diversity of ancient Indian contribution in different fields of S&T, the article would require a vast space to cover the whole subject and therefore it was prudent to break the article in two parts this being the first part. The second part of the article will cover all other subjects not covered in this part and will include subjects like mining and metallurgy, enduring art and architecture, traditional crafts, etc. while this part, the part 1 of the article, covers Indian contributions in the field of mathematics and philosophy, Harappans technological achievements, astronomy, alchemy and medicine, and other significant technological contributions that India made. This article also presents how this gallery was developed and the basis of choice of subjects covered and also the mode of the presentation.*

### Genesis

Since the dawn of human civilization, different cultures from across the world have contributed to the growth of science and technology, often through interactions. Science and technology in India originated and developed independently, and its

achievements are quite as profound as their counterparts in other advanced cultures. Indians developed one of the earliest written scripts (the Indus Scripts)<sup>1</sup> albeit un-deciphered completely, however there are now renewed efforts for deciphering the same<sup>2</sup>. Indians built urban towns, with residential complexes and wastewater systems, way back in 2500 BC. Ancient Indians created the concept of a perpetually moving machine in 624 AD and also produced the Delhi Iron Pillar<sup>2A</sup> that has remained rustless for the past 1500 years. They discovered the magic number zero and were the first to use decimal place value number system way back in 500 AD. Cotton Gin, an Indian invention, as credited by Joseph Needham, was the forerunner of all geared machines that subsequently paved the way for the west to bring about an industrial revolution. Indians also created enduring architectural constructs that have become eternal world heritages. They smelted zinc, which require precise metallurgical knowledge, on industrial scale and produced thousands of tons of zinc over hundreds of years<sup>3</sup>. There are several other contributions that scholars like Joseph Needham credits India to be the first to make, which include: alcohol distillation, use of scotch-bow, crank, draw-bar, milling and spinning-wheel<sup>4</sup> etc. Just as in other countries, including the western civilization, the progress of S&T in India has been anything but uniform in time and space. Periods of rapid advance have alternated with long periods of stagnation and even of decay. Science and technology in India closely intertwined with culture and philosophy, tempered with wisdom has flourished for centuries. However, strong influences of foreign invasions subdued it. We therefore had to rely on diverse reference materials and research content for the development of the gallery for portraying S&T Heritage of India in a manner easily comprehensible by the visitors.

### *The Challenges for Developing Historical Exhibitions in Science Centres and the Approach Adopted*

The challenge for the science centres to show case S&T culture of India spread across a vast span (more than 5000 years) in the most authentic manner is largely due to the diverse views, some of which are contrary to each other, expressed by different scholars. The challenge can best be appreciated in the expression

of Dr Frank Winter, a Smithsonian Institution (National Air and Space Museum) Curator, and an expert on the history of rockets, arms and ammunitions, who describes the research on Indian science and technology history as a "historian's nightmare". Fortunately for us we could develop this gallery laying the foundation on the scholastic research works already done by the Council while developing the Festival of India (FOI) exhibition in the 1980s. Large part of this exhibition was dedicated to the Indian S&T Heritage. This exhibition after successfully touring different science centres across USA and other countries finally was brought back to India. We therefore had a wealth of information and research material and also artifacts that we could use for the development of the gallery "Our S&T Heritage" at National Science Centre, Delhi (NSCD). The FOI exhibition was created in the early 1980s and its content was largely based on the research information and content available at that point of time and therefore the exhibition did have its own limitation more so since the field of archeo-metallurgy, archeo-astronomy and history of S&T in India has evolved rapidly and scores of research materials, books and monographs in different fields have been published. Several scholarly publications have also appeared in the "Indian Journal of History of Science" a quarterly journal brought out by INSA, which has also published books and periodicals and journals on the history of science and technology in India. Dholavira, a site belonging to the Indus Civilization has been excavated during the 1990s by Dr Bisht and these excavations have shed new insights into the Indus Civilization. Incidentally Nehru Science Centre, Mumbai one of the units of National Council of Science Museums, in the year 2006, opened a new gallery "Our Technology Heritage" and for developing this gallery lot of research was carried out for collecting research information and content and contacts were also made with leading scholars both national and international working in this field. This research content and information was highly useful in the development of the gallery at Delhi. In addition to the above mentioned research content further research was also carried out at NSCD and all this research content have been referred extensively while designing and developing the gallery. Besides these materials we also relied on other research publications from scholars like Dr Paul Craddock of the British Museum, who has done monumental work on archeo-metallurgy including zinc smelting from the Zawar mines, Dr R Balasubramaniam, IIT, Kanpur, whose "New Insights into the Delhi Iron Pillar", and his works on "Saga of Indian Cannons" has shed new light into the remarkable technological acumen that the ancient Indians possessed in forging and iron technology, Prof Ranganathan and Dr Sharda Srinivasan, of IISC Bangalore who have brought out a scholarly book "Legendary Wootz steel" that talks about the ancient

Indian contributions in the field of iron and steel with special emphasis on Wootz steel also served as useful reference. We have also been privileged to get support and obtain information from various scholars both from India and abroad for developing this gallery.

### *A Need for Needham like Publications for India*

Notwithstanding the volumes of information and research content that is now presently available in different sources related to the history of science and technology in India, yet the acceptance of ancient Indian contributions in science by the international community is far from what is desirable. This is mainly on account of the fact that there is no single scholarly publication that dwells on the history of science and technology in India. However, in the case of China, Joseph Needham, a leading scholar at Cambridge, made it his life's work to document China's history of science and technology ("Science and Civilization in China, Cambridge University Press" in over 30 volumes) (<http://www.nri.org.uk/science.html>). By the time he died at age 90, his works has transformed the study of China forever. The Needham Foundation has continued his monumental work after his death, and has been expanding the series with new volumes. No such singular effort has been made for documenting the contributions of India. Although in the recent past Infinity Foundation, an US based organization, has instituted leading scholars to publish a 20 volumes series of books under the project title HIST (History of Indian Science and Technology)<sup>5</sup>, out of which some publications have already been completed, yet much more is required to be done to reach anywhere near what Needham did for China. A series of essays on ancient science and technology in India written by well known authors also now find a place on the net<sup>6</sup> which also helps in spreading awareness among international audience.

Today, every research library on China, and every major library on science and history, has the Needham collection as important reference works. Every serious China scholar has respect for this work, and its impact on the image of China has been extraordinary. This impact has also trickled down to the depictions in schools and the general media. No longer is it easy for anyone to denigrate Chinese civilization as being devoid of rational thought, scientific rigour, or the quest for indigenous progress. It is because of this that most students have learnt about the ancient cities of the Middle East and China. But due to the absence of such scholarly work as that of Joseph Needham on Indian contributions in science and technology, many people

do not know even the basic facts about the ancient Indus Valley Civilization, one of the oldest and most advanced civilizations anywhere in the world. India has over 800 of the 1100 known sites discovered so far in the world yet not many are aware of this rich Indian heritage. Rustless wonder - the Delhi Iron Pillar, that has withstood corrosion for all of 1500 years or so is located in the precincts of Qutab Minar, yet many people even in Delhi are not aware of its uniqueness. It was in this context that a gallery on Our S&T Heritage was developed for creating awareness about the rich S&T Heritage of the country for the public.

Amartya Sen, summarizes the dichotomy that India faces when it comes to presenting its rich science and technology heritage. While referring to the contributions of Joseph Needham and necessity of such scholastic works for India he says, "Fear of elitism did not, happily, deter Joseph Needham from writing his authoritative account of the history of science and technology in China,..... A similar history of India's science and technology has not yet been attempted,..... The absence of a general study like Needham's is influenced by an attitudinal dichotomy. .... The need for a work like Needham's has remained unmet"<sup>7</sup>.

The need espoused by Amartya Sen for bringing out such monumental works similar to the one brought out by Joseph Needham on China to cover the contributions of India in science and technology got a momentum during the inauguration of Our Science and Technology Heritage gallery at our Centre. This gallery was inaugurated by Shri Jawhar Sircar, Secretary, Ministry of Culture, Government of India, on 21<sup>st</sup> October, 2009 and on seeing the contributions of ancient India in science and technology displayed in the exhibits, he felt that there should be a series of scholastic publications on the subject and announced that the Ministry of Culture, Government of India would soon take initiatives towards achieving this.

## Presentation Techniques

Exploratorium, a path breaking science centre built by the legendary Frank Oppenheimer, has revolutionized the concept of interactive exhibits and the Indian science centres too have adopted his philosophy like all the other science centres of the world, for presenting their science centre gallery exhibits in an interactive way. We therefore encountered another complex issue as to how we should approach presenting the exhibits in "Our S&T Heritage" gallery at NSCD. After series of brainstorming sessions with the curators and exhibition officers, we took a consensus decision to present this

gallery using a wonderful mix of both the science centre and traditional museum approach. The interactive exhibits used in the gallery were artistically crafted to merge with the traditional museum presentation in the gallery. In the museum like display most of the subjects covered in the gallery are showcased to present a period setting and thus taking the visitor back to the era of the period being covered.

## The Entry Mural

The gallery starts with a presentation that is a wonderful mix of both the science centre and museum approach (Fig1&2). A large size mural



Fig..1 The entrance view of the gallery showing inset display of the section on ancient astronomy



Fig. 2. Time line of our S&T Heritage mural exhibit in the entry area showing 6 landmark time lines with supporting digital photo frames and a touch screen multimedia

encompassing land mark developments from the Mehrgarh culture (7000 BC) to the Mogul era (1750 AD) has been displayed with some landmark features of science and technology depicted in the mural. Some of the other important landmark features of the period not covered in the mural are appropriately covered in the accompanying digital photo frames that appear one at a time. A multimedia touch screen computer and a large size display unit supplement the exhibit to cover detailed information on total time span of our S&T Heritage.

## Technological Traditions of Indus – Diorama

The next section in the gallery (Fig 3) portrays in a period setting, with artistic elegance, the technological developments of the Indus Valley Civilization. It is for this reason that Harappans have



Fig. 3. A general view of the Harappans diorama showing different technological practices of the Indus people

been referred to as remarkably sophisticated and industrialized urbanites of the Bronze Age in south Asia<sup>8</sup>. Important technological traditions of the Harappans have been recreated with life like human figures adopting the references from the works of Kenoyer of the University of Wisconsin<sup>9</sup>. Technologies showcased in the exhibit include: pottery and ceramics, shell bangles, carnelian beads, metallurgy, precision hole drilling in beads, town planning, textiles, drainage, pounding platforms, ship building and dock yard, market place with standardized weights and measures etc. A show case has also been created to display the replicas of pottery and other important material evidence from the Indus valley findings. Two multimedia computers with touch screens have been used in the presentation to show case the technological traditions of the Harappans one each in English and Hindi language.

The Indus Valley Civilization, at its peak during 2600 BC to 1900 BC, knit together more than 1000 cities, towns and settlements scattered across 725,000 sq km of India and Pakistan<sup>10</sup>. The Indus Valley Civilization, also called the Harappan Culture was according to some, the youngest but by far the largest of the three most ancient civilizations. It was noted for wheel turned ceramics, terracotta craft, spinning and weaving, bead-making, and more importantly, copper-bronze casting by the *cire-purdue* or lost-wax process. Within this civilization flourished many towns and cities including Mohenjodaro, Harappa, Dholavira, Chanhudaro, Kalibangan, Lothal etc which have revealed an agriculture-based economy with granaries and other storing techniques that made for an enriched community life.

The Indus cities show town planning of an amazing complexity<sup>11</sup>. Systematic town planning, fortification of citadel, lower town, elaborate drainage system, establishment of granaries and surplus economy, standardization of brick sizes, weights and measures, use of geometric instruments like right angles, linear scale and plumb bob etc are the principal gifts of the Harappans to the succeeding cultures. The Harappans gave the idea of welfare for the workers by establishing workmen's quarters. City houses in matured Indus Valley stage has been many-storied, palatial, solidly built imposing walls of well-baked bricks with 4:2:1 size ratio, which now forms the basis for modern English and Flemish brick bonding, and supplied with such amenities as good bathroom and lavatories. Besides the straight roads meeting at right-angles, there was a superb drainage system for carrying away rain-water and cesspools for clearing the sewage. Studies have also shown that starting from the Indus Valley Civilization up to the construction of Iron Pillar, India used standard length unit of *angulam* (close to an inch) over a period of almost 3000 years. No other ancient civilization offered civic amenities of such complexity.

## Mathematics and Early Philosophical Sciences

The next section (Fig 4) covers the mathematics and philosophical concepts that emanated from India. Here too an inextricable mix of science centre and museum approach has been adopted to present the subject. A process apparently as simple as counting has passed through many stages before reaching the present level of universal acceptance. India gave to the world an ingenious method of expressing all numbers by means of symbols, each symbol representing a value of position as well as an absolute value, a profound and



Fig 4. A general view of the section on Ancient Indian Philosophical concepts and contributions in mathematics

important idea that appears so simple now that we tend to ignore its true merit. George Sarton, the renowned historian of science, known for his work, *Ancient science through the golden age of Greece*, Cambridge, Harvard University Press, 1952, has observed: *Our numbers and the use of zero were invented by the Hindus and transmitted by Arabs; hence the name Arabic numerals which we often give them.* Al-Khwarizmi (9<sup>th</sup> century AD), a Central Asian mathematician who worked in Baghdad, played a crucial role in transmission of the Hindu works to the western world through his seminal work on arithmetic. Al-Biruni (11<sup>th</sup> Century AD)<sup>12</sup> was another exponent not only of the Hindu numerical system, but also of Indian astronomy. Other important Indian contributions that have been adequately covered in this section of the gallery include calculation of the value of pi, and calculating the square and cube roots of numbers, the golden rule of three, Brahma Gupta's important contribution in the solution of second order indeterminate equation that was later recognized by Europe as the Pell's equation. His lemmas in this connection were rediscovered by Euler (1764) and Lagrange. The so-called Pythagoras theorem also seems to have been worked out by the Indians as evidenced in the *Sulbasutra* treatises and therefore the exhibition also covers this aspect which also has been presented in an interactive manner.

A thousand years before the time of Copernicus (1473-1543), Aryabhatta (476 AD) in India made outstanding contributions to astronomy and mathematics. His contributions include: the determination of the diameter of the earth and the moon, the proposal that the earth rotated on its axis to explain the daily motions of the fixed stars; the solution of quadratic equation; defining the trigonometric functions; stressing the importance of Zero; and determining the value of pi up to the fourth decimal place. The tradition of astronomy and mathematics

continued in the years to come, preceding similar developments in Europe by a couple of centuries in such areas as determination of the precision of equinoxes, parallax, mean and true motions of planets, permutations and combinations, solving quadratic equations, square root of negative numbers and trigonometrical series brought out by Madhava and others of the Kerala school of mathematics. The twelfth century witnessed the most notable astronomer-cum-mathematician, Bhaskaracharya II. His cyclic (*chakravalaya*) method for solving indeterminate equations of the second order has been hailed by the eminent German mathematician Hermann Henkel as the finest thing achieved in the theory of numbers before Lagrange. Each of these abstract concepts and contributions has been presented in the exhibits in a manner that has an interactive component for the visitor to try his/her hands on.

### Alchemy- The Rasashala

Alchemy (the older form of chemistry) is another area in which ancient Indians made profound contributions<sup>13</sup>. It is interesting to note that Joseph Needham claims that earliest distillation of alcohol can be traced back to the archaeological finds at Taxila<sup>14</sup>. Much of ancient chemistry in India grew out of the early efforts to develop an elixir and to turn base metals into gold. The Indian alchemy had two characteristic streams: gold making and elixir synthesis. The two faces of the alchemical practice, the metallurgical and the physico-religious, were superimposed to get a single picture wherein mercury and its elixirs were used in the so-called transmutation of the base metals into noble ones, as well as for internal administration for purifying the body, rejuvenating it and taking it to an imperishable and immortal state. The earliest available documented alchemical text in Sanskrit, *Rasaratnakara* by Nagarjuna was probably part of a larger text *Rasendramangala* written by the same author. Nagarjuna was the most prominent scholar in the field of Indian alchemy. Rasashala (fig 5), a typical



Fig 5. Exhibit showing a typical period setting of an ancient chemical laboratory the Rasashala

alchemical laboratory of Nagarjuna which is portrayed in the Gallery, shows a number of special types of *yantras*, used for different chemical purposes like distillation (*patanayantra*). One of the most important *yantras* the *tiryakapatanayantra* (reverse distillation) was used in zinc smelting and also in the perfume making (fig 6). In ancient India, there was



Fig. 6. Diorama depicting the ancient Indian perfume making process using the reverse hydro distillation techniques

considerable use of cosmetics and perfumery for the purpose of worship, sale and sensual enjoyment. *Brihatsamhita* (500 AD) of Varahamihira deals with *gandhayukti* (blending of perfumes) in 37 verses. The word *sugandhi*, meaning well perfumed, is also used in Rig Veda. Expressions involving the term *gandha* are found in *Taittiriya Samhita*, *Maitrayani Samhita*, *Satapatha Brahmana* and *Taittiriya Aranyaka*. The ancient traditional method of making the *attar* using hydro distillation is still used at *Kanauj*. Attars of Kanauj are widely acclaimed by the world both as perfumes and medicines.

## Medicine and Surgery

The science of the body and mind, in India, had its origin in the healing art of the Vedic times. This knowledge and practice, called *Ayurveda*, meaning 'Science of Life' originated in ancient India. Although the era in which Ayurveda originated is embroiled in controversy it is fairly certain that it is one of the earliest medical sciences to have evolved globally. *Rigveda* and *Atharvaveda*, the earliest documented ancient Indian knowledge, have references on health and diseases. Ayurveda deals elaborately with measures for healthful living during the entire span of life and its various phases. Besides, dealing with principles for maintenance of health, it has also developed a wide range of therapeutic measures to combat illness. These principles of positive health and therapeutic measures relate to physical, mental, social and spiritual welfare of human beings. Ayurveda is broadly classified under three major categories

namely, *Charaka Samhita* (probably authored by Charaka), *Sushruta Samhita* (authored by Sushruta) and *Asthanghrudaya* (by Bhagavata).

The *Charaka Samhita* is believed to have arisen around 400-200 BC. It is felt to be one of the oldest and the most important ancient authoritative writings on Ayurveda. It is not known who this person, Charaka, was or, if indeed, this represents the work of a "school of thought." It could have been from a group of scholars or followers of a man known as Charaka or an original composition from a single person named Charaka. This work is sometimes considered a redaction of an older and more voluminous work, *Agnivesha Samhita* (46,000 verses), which is no longer extant. Dridhabala, living about 400 AD, is believed to have filled in many verses of missing text in the *Chikitsasthana* and elsewhere, which disappeared over time. The study and understanding of several classical treatises on Ayurveda indicate presence of eight disciplines which are generally called "Ashtanga Ayurveda" and these eight disciplines include: Internal Medicine (*Kaya Chikitsa*), Paediatrics (*Kaumar Bhritya*), Psychiatry (*Bhoot Vidya*), Otorhinolaryngology and Ophthalmology (*Shalakya*), Surgery (*Shalya*), Toxicology (*Agad Tantra*), Geriatrics (*Rasayana*) and Eugenics and aphrodisiacs (*Vajikarana*). The language of Charaka Samhita is Sanskrit and its style is poetry. Poetry was known to serve as a memory aid. Charaka contains over 8,400 metrical verses, which are often committed to memory, by the medical students of Ayurveda.

The *Charaka* and *Sushruta Samhitas* present a vivid and cogent account of the medical knowledge and surgical practices respectively and continue to be used in Ayurveda even today. Medical historian D. Guthrie records, *it was in surgery; above all, that the ancient Hindus excelled*. Noted physician, Galen of Pergamum who lived in Rome, made no secret of his borrowing material relating to ointment for the eyes and the Indian plaster from Indian sources. The *Sushruta Samhita* which accords pride of place to surgery describes more than three hundred different operations and 121 surgical instruments (20 sharp and 101 accessory) such as tongs, forceps, scalpels, catheters, syringes, speculums, needles, saws, probes, scissors and the like. Most of the surgical instruments used by Sushruta are quite similar to the modern surgical instruments<sup>15</sup>. The outstanding feats of ancient Indian surgery related to laparotomy, lithotomy and plastic operations. The *Sushruta Samhita* is regarded as the earliest document to give a detailed account of rhinoplasty (plastic reconstruction of the nose). It was only in the eighteenth century that plastic surgery made its appearance in Europe. This aspect of ancient Indian Surgery has been aptly presented in the gallery in the form of a diorama depicting a typical surgical room of Sushruta (fig 7).



Fig 7 Diorama showing a typical surgical laboratory of Sushruta, with supporting information and display materials

Of the several media coverage that the gallery received in the print and electronic media one that stands out is the coverage on Sushruta's surgery. Just after the inauguration of the gallery a press correspondent from AFP, of all things from the gallery, picked up the *Nose Job* of Sushruta and filed his report and his report was picked up and published by several international and Indian print medias<sup>16</sup> and the coverage credited India (Sushruta) to be the first to carry out the plastic surgery with specific reference to the rhinoplasty, besides touching upon the other highlights of the gallery.

## Significant Technological Contributions of India

### Noria and Saquia

One of the major additions to the newly developed gallery at NSCD was the Indian Technological contributions in the field of milling, water lifting devices, worm gearing, crank, scutch bow, and spinning wheel<sup>17</sup>. Joseph Needham in his *Science and Civilization in China*, besides concentrating on China, also bases his studies in a world view context and has touched upon the contributions of other civilization on China. He also touches upon the Indian contributions in cavalry equipment and the gun powder epic<sup>18</sup> and about Navigation<sup>19</sup>.

Water lifting devices were one of the important technological achievements in man's quest for progress. Ancient Indians were the first to introduce the water lifting devices. There is definite and conclusive evidence that water pot device – *chakkavattaka* or *Ghati Yantra*, an Indian term for Noria - the water lifting device, existed in India as early as 4<sup>th</sup> Century BC. Needham describes<sup>20</sup> two forms of water lifting devices the Noria and Saquia, and further elaborates that Noria is a water lifting device that contains fixed pots or containers on the rim of the wheel and Saquia on

the rope or the chain flung over the wheel. He further says, based on the works of two other scholars Ananda Coomarsamy<sup>21</sup> and Laufer that India was the country where the Noria originated from<sup>22</sup>.

In India water lifting devices were referred to as *chakkavattaka* (turning wheel) during the *Cullavagga Nikaya* period (assigned to 350 BC). It was one of the three permissible models for water lifting. Another term *arahattaghatiantra* ("A well-wheel with water-pots attached to its spokes") has also been used in ancient Indian texts for water lifting devices. It is clear that since *ara* means "spoke" and *ghata*, means "earthen pot", *araghata* or, in its Prakrit forms, *arahatta* or *arahattaghati*, must mean a wheel "with earthen pots on the spokes". This definition substantiates that *chakkavattaka* refers to the Noria. Noria and Saquia the two water lifting devices, have been depicted in the gallery using diorama setting type display (fig 8).



Fig 8. Diorama showing the early water wheels in India, the *chakkavattaka* or *ghatiyantra* called the Noria an Arab water lifting device which has its origin from India

## Worm Gearing and Crank

Needham<sup>23</sup> also proposed that the worm gearing device, a highly technologically significant device and the most ancient form of rolling mill, originated in India. His argument was based on the presence of the *charkhi* or cotton-gin, with two elongated worms serving to turn its rollers in opposite directions, in parts of China. Noting its presence in Indo-China and Xinjiang, Needham further

speculated that it reached China from India by two routes, via Burma and Indo-China, in about the fifth century AD and, via Central Asia, in the thirteenth. This would mean that the cotton-gin must have been in use in India before the sixth century AD. Needham's hypothesis of the worm gear originating in India was substantiated by Schlingloff<sup>24</sup> who identified the scene, in an Ajanta painting on the left wall of Cave I to the left of the second cell-door, as one of cotton-processing activities and believed that the painting represented a scotching bow. Ishrat Alam<sup>25</sup> however has rightly identified it with the Indian cotton gin thus establishing the fact that the cotton-gin originated in India before the 6<sup>th</sup> century AD. This aspect of the invention of cotton-gin in India becomes more certain because of the universal acceptance that cotton cultivation began in India and that it dates back to the Harappans times. Research scholars have pointed out that the demand for Harappans cotton by the contemporary communities of Iran and Mesopotamia increased the cultivation of cotton by the Harappans which led to an urban revolution. It is therefore not surprising that the concept of an important technology of use of worm gearing began in India with the introduction of the Cotton-Gin and this aspect of India to be the origin of the cotton-gin is best eschewed in the words of Needham who says 'In this machine (cotton-gin) we must surely recognize the most ancient form of rolling mill, a mechanism destined to have such importance later in metal technology'. While presenting this concept in the gallery we have covered the cotton-gin and textiles under single exhibit (fig. 9) and highlighted



Fig 9. Exhibit display showcasing ancient Indian cotton and textiles with information on cotton-gin and also a model of the same in the inset along with other display

the significance of cotton, cotton-gin and also the rich traditional textile heritage that India has. The exhibit also houses a model/replica of an ancient cotton gin made from the references of Needham's book.

(to be concluded in Part II)

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# Genomics: Introduction and Applications to Human Health

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## Abstract

Genomics is the study of the collective genetic material in an organism. This discipline is mainly focused on sequencing the DNA in an organism to form a complete picture. By sequencing the entire DNA pattern of an organism, scientists can generate a great deal of information. The genomes of numerous species have been sequenced, from bacteria to humans. The genome of each species is distinctly different, with varying numbers of nucleotides. Within a species, genetic variation may be minimal, but still interesting, because it can explain certain traits or tendencies. Genomics is greatly contributing to our knowledge of human health and understanding of disease. Current genomics research is focused on studies to discover association of genomic variants with disease and use of this knowledge in developing molecular diagnostics.

"We used to think our fate was in our stars. Now we know, in large measure, our fate is in our genes." **J. D. Watson**, Nobel laureate, Physiology or Medicine (1962).

## 1. Introduction

Living organisms may be of two types: prokaryotes and eukaryotes. The prokaryotes are a group of organisms that lack a cell nucleus. They differ from the eukaryotes, which have a cell nucleus. For example, Bacteria are prokaryotes, whereas Humans are eukaryotes. In these cells, the genetic material is the DNA. DNA usually occurs as linear chromosomes in eukaryotes, and circular chromosomes in prokaryotes. The information carried by DNA is held in the sequence of pieces of DNA called genes (fig. 1). The genome is the whole hereditary information of an organism that is encoded in the DNA (or for some viruses, in the RNA).

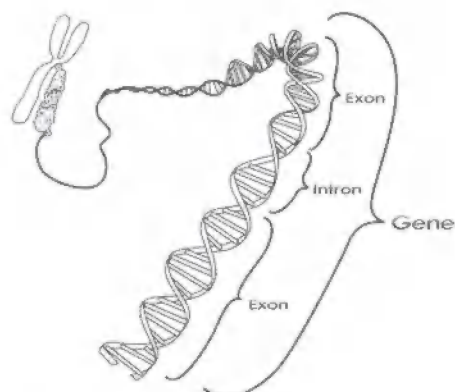


Fig. 1. Gene is a small fraction of DNA

The human genome has approximately 3 billion base pairs of DNA arranged into 46 chromosomes. Genomics is the comprehensive study of the genetic information of a cell or organism.

A gene is a unit of heredity and a region of DNA that influences a particular characteristic in an organism. Genes contain an open reading frame that can be transcribed, as well as regulatory sequences such as promoters and enhancers, which control the transcription of the open reading frame. In many species, only a small fraction of the total sequence of the genome encodes protein. For example, only about 1.5% of the human genome consists of protein-coding exons, with over 50% of human DNA consisting of non-coding repetitive sequences. The reasons for the presence of so much non-coding DNA in eukaryotic genomes and the extraordinary differences in genome size, among species represent a long-standing puzzle. However, DNA sequences that do not code protein may still encode functional non-coding RNA molecules. Among functional RNA molecules, siRNA technology is being applied in many laboratories to assess the roles of genes by loss-of-function phenotype analyses.

## 2. Genome-oriented Basic Research

### (i) Genome Sequencing

The sequence of DNA encodes the necessary information for living things to survive and reproduce. Determining the sequence is therefore useful in fundamental research into why and how organisms live, as well as in applied subjects. Because of the key nature of DNA to living things, knowledge of DNA sequence may be useful in practically any biological research.

The first free-living organism to be sequenced was that of *Haemophilus influenzae* (1.8 Mb), a bacterium in 1995<sup>1</sup>, and since then genomes are being sequenced at a rapid pace. As of now, the complete sequence is known of many viruses, bacterial species and eukaryote organisms. Most of the bacteria whose genomes have been completely sequenced are problematic disease-causing agents, such as *Haemophilus influenzae*. Of the other sequenced species, most were chosen because they were well-studied model organisms or promised to become good models. Yeast (*Saccharomyces cerevisiae*) has long been an important model organism for the eukaryotic cell, while the fruit fly *Drosophila melanogaster* has been a very important tool (notably in early pre-molecular

genetics). The worm *Caenorhabditis elegans* is an often used simple model for multicellular organisms. The zebra fish *Brachydanio rerio* is used for many developmental studies on the molecular level and the flower *Arabidopsis thaliana* is a model organism for flowering plants. The Japanese pufferfish (*Takifugu rubripes*) and the spotted green pufferfish (*Tetraodon nigroviridis*) are interesting because of their small and compact genomes, containing very little non-coding DNA compared to most other species. The mammals like dog (*Canis familiaris*), brown rat (*Rattus norvegicus*), mouse (*Mus musculus*), and chimpanzee (*Pan troglodytes*) are all important model animals in medical research.

## (ii) Genome-wide Association Studies

A genome-wide association study (GWAS) is an examination of genetic variation across a given genome, designed to identify genetic associations with observable traits. In human studies, this might include traits such as blood pressure or weight, or why some people get a disease or condition. The completion of the Human Genome Project in 2003 made it possible to find the genetic contributions to common diseases and analyze whole-genome samples for genetic variations that contribute to their onset<sup>2</sup>.

These studies normally require two groups of participants: people with the disease (cases) and similar people without disease (controls). After genotyping each participant, the set of markers, such as SNPs (Single Nucleotide Polymorphism), are scanned into computers. Then bioinformatics is applied to survey participants' genomes for markers of genetic variation. If genetic variations are more frequent in people with the disease, the variations are said to be "associated" with the disease.

## (iii) DNA Microarray

A DNA microarray is a multiplex technology used in molecular biology and in medicine<sup>3</sup>. It consists of an arrayed series of thousands of microscopic spots of DNA oligonucleotides, called features, each containing picomoles of a specific DNA sequence, known as *probes* (or *reporters*). This can be a short section of a gene or other DNA element that are used to hybridize a cDNA or cRNA sample (called *target*) under high-stringency conditions. Probe-target hybridization is usually detected and quantified by detection of fluorophore-, silver-, or chemiluminescence-labeled targets to determine relative abundance of nucleic acid sequences in the target. Since an array can contain tens of thousands of probes, a microarray experiment can

accomplish that many genetic tests in parallel. Therefore, arrays have dramatically accelerated many types of investigation (fig. 2).

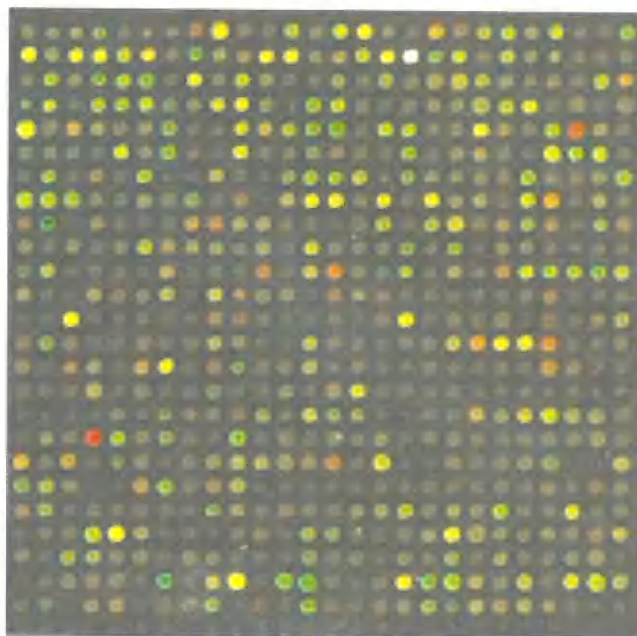


Fig. 2. DNA Microarray allows to study many genes in one experiment

## 3. Applications

The afore-mentioned genome-oriented basic research has been applied in all aspects of human health. Genomics plays a role in nine of the ten leading causes of death, most notably cancer and heart disease. These diseases are partly the result of how genes interact with environmental and behavioral risk factors, such as diet and physical activity. Also, a large fraction of children's hospitalizations are due to diseases that have genetic components. We shall outline three most important areas below:

### (i) Determining genetic contributions to diseases

#### a. Genes and disease

Genes can have a powerful impact on our health, sometimes directly - through chromosome or single gene disorders - or by influencing our susceptibility to disease. The role of genes in inherited disorders is well understood. For some diseases, one particular gene has such a major effect that mutations in it are said to 'cause' the disease. In most cases, however, there is no major single determinant. Instead, variations in many different genes contribute to disease susceptibility (fig. 3).

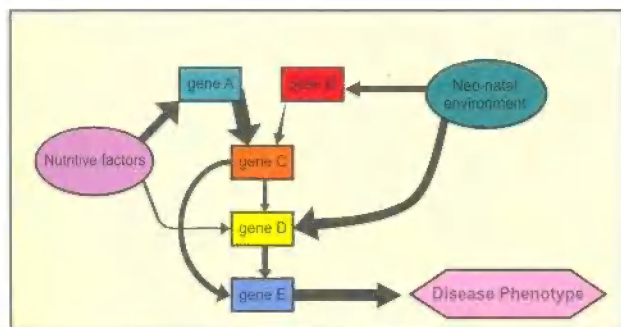


Fig. 3. Different genes can interact to cause disease

However, the extent to which genes contribute to disease varies and much remains to be learned. Advances in understanding the genetic mechanisms behind these diseases enable the development of early diagnostic tests, new treatments, or interventions to prevent disease onset or minimize disease severity. All diseases have a genetic component. Mutations may be inherited or developed in response to environmental stresses such as viruses or toxins. The ultimate goal is to use this information to treat, cure, or if possible, prevent the development of disease<sup>4</sup>.

## b. Major Types of Genetic Diseases

Many, if not most, diseases have their roots in genes. Genes, through the proteins they encode, determine how efficiently foods and chemicals are metabolized, how effectively toxins are detoxified, and how vigorously infections are targeted. Genetic diseases can be categorized into three major groups: single gene, chromosomal abnormalities, and multifactorial (or complex conditions).

Thousands of diseases are known to be caused by changes in the DNA sequence of single gene. A gene can be changed (mutated) in many ways resulting in an altered protein product that is unable to perform its function. The common gene mutation involves a change or "misspelling" in a single base in the DNA like in sickle cell anemia (fig 4). Other mutations

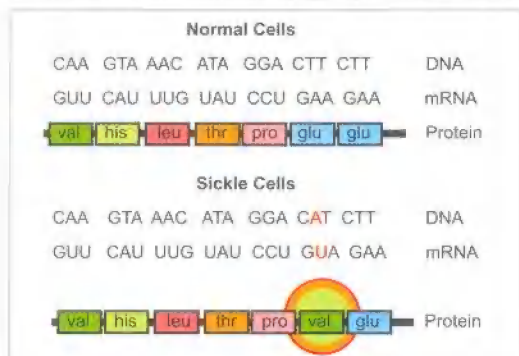


Fig. 4. A single amino acid in the beta chain is altered in sickle cell hemoglobin

include the loss (deletion) or gain (duplication or insertion) of a single or multiple bases. The altered protein product may still retain some function but at a reduced capacity. In other cases, the protein may be totally disabled by the mutation or gain an entirely new but damaging function. The outcome of a particular mutation depends not only on how it alters a protein's function but also on how vital that particular protein is to survival.

In addition, genetic diseases can be caused by larger changes in chromosomes. Chromosomal abnormalities may be either numerical or structural. The most common type of chromosomal abnormality is known as aneuploidy, an abnormal number of chromosomes due to an extra or missing chromosome. A normal karyotype (complete chromosome set) contains 46 chromosomes including an XX (female) or XY (male) sex chromosome pair. Structural chromosomal abnormalities include deletions, duplications, insertions, inversions, or translocations of a chromosome segment (fig. 5).

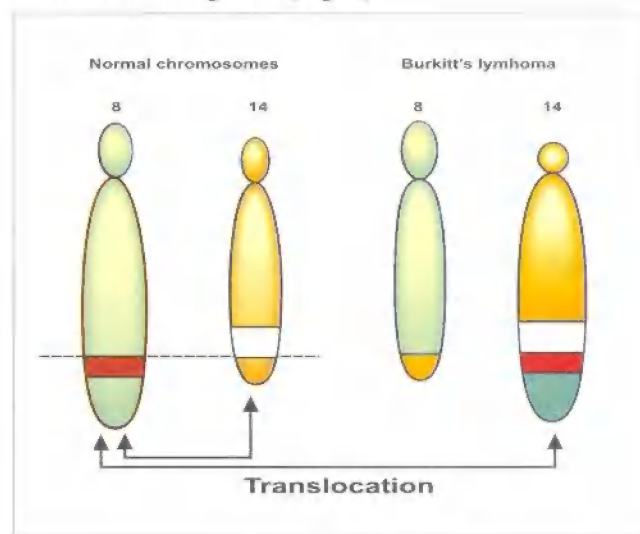


Fig. 5. Reciprocal chromosomal translocations in Burkitt's lymphoma, a tumor of B lymphocyte

Multifactorial diseases are caused by a combination of genetic, behavioral and environmental factors. The underlying etiology of multifactorial diseases is complex and heterogeneous. Examples of these conditions include spina bifida (split spine), diabetes, and heart disease. While multifactorial diseases can recur in families, some mutations can be acquired throughout an individual's lifetime such as in cancer. All genes work in the context of environment and behavior. Alterations in behavior or the environment, such as diet, exercise, exposure to toxic agents, or medications can all have influences on genetic traits.

### *(ii) Developing biomarkers for Tissue Classification by microarray*

DNA microarray technology provides useful tools for profiling global gene expression patterns in different tissue samples say healthy and diseased persons. In such experiments, sufficient numbers of arrays are employed for both the conditions. After the experiment, data is organized properly. First of all, differentially expressed genes between two conditions are identified. One major challenge is the large number of genes relative to the number of samples (arrays). The use of all genes can suppress or reduce the performance of a classification method. Selection of an optimal subset from the differentially expressed genes becomes an important pre step in sample classification. This can be achieved by using a suitable feature selection method. Once significant genes highly correlated with tissue types are identified, all available classification methods may be used for classification of tissue samples. The selected genes for classification after validation may be used as biomarkers<sup>5</sup>.

### *(iii) Use of microarray data for drug discovery*

Currently, Systems biology approaches to disease are developed from the idea that disease-perturbed regulatory networks differ from their normal counterparts. Microarray data analyses reveal global changes in gene expression in response to genetic and environmental changes and accordingly, are well suited to construct the normal, disease-perturbed and drug-effected networks, which are useful for drug discovery<sup>6</sup>.

## **4. Promise of Personalized Medical Treatment**

Six years after scientists finished decoding the human genome - the genetic instruction book for life - they are starting to take their new knowledge from the research laboratory to the doctor's office and the patient's bedside. Researchers are seeking ways to tailor treatments to individuals - they call it "personalized medicine" - in order to improve patient outcomes and to lower costs in the overburdened health care system. The goal is to deliver the right drug at the right time in the right dose to the right person, and eliminate treatments that do not work. Researchers say that personalized medicine also can reduce unnecessary suffering and expense by minimizing the chance of adverse drug reactions.

Experts caution, however, that it is premature to say that an era of individually customized medicine has arrived. Major scientific and policy hurdles remain

before patients can benefit widely from the promises of personalized medicine. Issues of insurance coverage, medical training, privacy and safety remain to be resolved<sup>7</sup>.

Costs of decoding the genome have come down proportionately. In 2003, it cost an estimated \$300 million to decode the first genome of an individual human. By 2007, the cost per person had come down to \$100 million, and by 2008, it was \$60,000. The current cost is about \$20,000. It is predicted that it soon will be possible to sequence a person's genome in one day. For the first time, this will enable large numbers of patients to be sequenced to get to the bottom of thousands of genetically controlled diseases.

## **5. Challenges in Translation of Basic Scientific Discoveries into Healthcare**

- \* Physicians feel unprepared to integrate genomics into regular practice. Education of health professionals must be a priority to advance the use of genomics into healthcare. With the rapid advances in genomics research and developing technologies, it will be challenging to keep health professionals informed about the benefits, risks, and limitations of new tools as they become available. Basic genomic literacy is a critical need for patients, physicians, and communities to engage in genomic research, and clinical studies are required to bring about a change in the care paradigms to support clinical genomics applications.
- \* Consumers are worried about the possible adverse consequences of genetic testing, particularly the privacy issues and discrimination against receiving employment and health insurance. In order for genomic medicine to be integrated into routine clinical practice, associated fears with this type of testing must be put to rest.
- \* Public-private partnerships will likely be required to generate the evidence base for genomic medicine. These collaborations are desirable because firstly, no single stakeholder group is likely to have sufficient resources or expertise to conduct the necessary studies, and secondly, both will likely benefit from their execution.
- \* As with any new innovation, genomic testing must be demonstrated to be clinically useful, cost-effective, and of value. Clarity is needed on the drivers of cost effectiveness of genomic technologies.

- \* The gaps to be filled to bring genomic medicine to fruition are exceedingly complex. There is a need for developing a clear understanding of pathways for translation, the barriers that lie in the translational path, and the strategies to overcome them.

## 6. A Brief Account of Indian Achievements in Genomics:

The devastating growing population due to high birth rate and blood related marriages favoured in many Indian communities cause prevalence of genetic disorders in India. The demographic factor provided a sound ground to carry out research in the field of Molecular biology and genetics in India. The 15<sup>th</sup> International Congress of Genetics was held in New Delhi in 1983 under the Presidentship of Dr. M. S. Swaminathan. This event sensitized the science policy makers in India to make investments in genetic research. Accordingly, India has taken important steps in creating the basic infrastructure of molecular biology research in the country, with the Department of Biotechnology (DBT) playing a major role in this endeavour. The DBT has established nine research institutes at various places of the country. These institutes are well equipped with world-class instrumentation and highly competent human resources. Some other organizations such as CSIR, ICAR, ICMR, MOEF, UGC/academic institutes, DAE and some NGOs have also joined hands with the DBT to endorse the research in the field of Molecular biology and genetics.

As a follow up to the 1983 Congress, Genetics Congress Trust was set up, with the main objective of promoting molecular genetics research in India. A symposium was organized by the Genetics Congress Trust in New Delhi during 21-22 January 2004 to discuss how India has fared during the Post-Genetics Congress period<sup>8</sup>.

Of late the contributions of Indian scientists in this rapidly developing discipline have been recognized. Indian scientists from Delhi University, CSIR, ICAR etc have added many feathers to India's efforts in this area. Below we summarize the major achievements:

1. Department of Biotechnology (DBT) and Indian Council of Agricultural Research (ICAR) jointly laid down the foundation of the Indian Initiative for Rice Genome Sequencing (IIRGS). The map-based sequence of the rice genome was completed in December 2004 and published in Nature on August 11, 2005<sup>9</sup>.

2. Two years ago, a team of Indian scientists from Hyderabad and New Delhi had sequenced the full genome of a harmless bacterium that has been named *Mycobacterium indicus pranii*.

3. Early last year, CSIR had successfully completed the whole genome sequencing of a wild type strain of Zebra fish (*Danio rerio*). This work marked India's entry into the arena of whole genome sequencing of animals. Zebra fish is popularly used by the scientific community as an organism for modeling human diseases.

4. A recent study published on 24<sup>th</sup> September 2009, led by scientist from Harvard and the Centre for Cellular and Molecular Biology (a constituent lab under CSIR) in Hyderabad, have determined that a large percentage of Indian population has originated from two sets of relatively few individuals. The primary ancestral groups have been identified as "Ancestral North Indians" (ANI) and "Ancestral South Indians" (ASI). This finding may have implication in health care of Indian population<sup>10</sup>.

5. In December 2009, Scientists of Institute of Genomics and Integrative Biology (IGIB), New Delhi have succeeded in completely sequencing the genome of an individual, enabling India to join a league of selected countries: the U.S., the U.K., Canada, China and Korea<sup>11</sup>.

## Conclusion

The sequencing of the human genome and many microbial genomes has provided new opportunities to study the genetic impact on life processes, leading to development of new technologies that can be translated to clinical practices. Developments of such new technologies take lot of time and resources because of their multidisciplinary nature. We have to take genomic research to its most important end point of improving human health. In India, Science policy makers are giving due importance to Genomics and the field is flourishing satisfactorily<sup>12</sup>. This will change the whole scenario of medical treatment as Caleb Parry, a visionary British physician of the 18<sup>th</sup> century said, "It is much more important to know what kind of patient has a disease than to know what kind of disease a patient has."

## Acknowledgements:

We thankfully acknowledge various resources on the internet which we have used in preparing this article. The views and opinions expressed in this article

are those of the authors and do not reflect the views of the organizations where they serve.

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## Captive Breeding of Butterflies

Techniques adopted at Regional Science Centre, Guwahati

S. Jeelani

### Abstract

For the first time in India, experiments in Captive breeding of butterflies started with scientific approach at National Council of Science Museums, Kolkata (NCSM) in the year 1993. After four years of continuous experimentation, first captive breeding facility of the country was established at Science City, Kolkata and second such effort was undertaken at Regional Science Centre, Guwahati. Captive breeding of butterflies needs well planned houses, climate control measures, larval food plant nursery etc. Besides these, techniques to rear and protect caterpillars, pupa and butterflies, keeping butterfly houses free from pests, quarantine methods to be adopted, butterfly handling techniques and production management, play crucial role in sustained breeding of butterflies. Techniques used in breeding of butterflies like Common mormon (*Princeps polytes*), Lime butterfly (*Princeps demoleus*), Plain tiger (*Danaus (Anosia) chrysippus*), Common crow (*Euploea core*), Psyche (*Leptosia nina*) Common grass yellow (*Eurema hecabe*) were discussed in detail in this paper. Role of butterfly gardens in imparting environmental education and ecological conservation programmes of Science Centre were also discussed.

### Introduction

Butterflies are also called flying flowers. People of all age groups love them alike because of their colours and beauty. There are many butterfly parks both in open and captive all over the world. These parks are run by many Zoos and private breeders. This is being done by zoos to create awareness about butterflies among people and private breeders for economical purposes. Large scale illegal trading of butterflies by means of catching them from wild, habitat destruction and pollutants in the atmosphere affecting these creatures immensely. All round efforts are being made in various countries to stop such practices by way of making laws and creating awareness among students and general public. Till recent past, no such efforts were undertaken in India.

Although there are some studies on butterflies, they are mostly dealt with morphology of butterflies, their habitats and behaviour. Not many studies are there on breeding of butterflies in the Indian context, specially on captive breeding. First scientific effort was started in India in NCSM in the year 1993 for the species

which are not in any schedule of Wild Life Act 1972. To begin with, caterpillars of different species were reared in coffee cups by providing larval food plant leaves. In the year 1997, first butterfly house was developed to breed common species of butterflies which are not in the wildlife schedule, in order to create awareness among general people and students at Science City premises. It was a success and visitors appreciated this effort. In 2004, second such effort was taken up at Regional Science Centre, Khanapara, Guwahati with the experience gained at Science City in captive breeding of butterflies. In 2006, another butterfly breeding facility came in Bangalore Zoo, Bannerghatta.

### Butterfly House and Caterpillar Nursery

A 15' H x 30' L x 15' W butterfly house was built with transparent resin sheet on the roof to receive maximum natural sunlight. Temperature (28°C–32°C) and humidity (80%–90%) maintained in the butterfly house. All the doors and windows are fitted with stainless steel wire mesh. Mesh size of these nets are 2 mm so that no predators can enter inside the house. Inlet and exhaust fans are fitted to provide natural air flow inside the house. Butterfly house and nursery are fitted with metal halide lights to provide near day light conditions. Mud puddles, nectar feeders and flowery plants along with natural plants are arranged inside the house. Caterpillar and Pupa Nursery is fitted with



Fig. 1. Butterfly House (outside)

climate control equipment along with caterpillar rearing and pupa boxes. Temperature and humidity maintained in the nursery are 28°C–32°C and 80%–95% humidity respectively. It is found that these



Fig. 2. Butterfly House (inside view)

climatic ranges gave best results when the caterpillars are growing and also during hatching of butterflies.

## Climate Control Methods

Both butterfly house and nursery were climatically controlled in order to provide best suitable conditions for butterflies. Besides this, recreated real natural environment is made to prevent predators from entering in to these houses and to keep them free from pollutants. This helped in keeping suitable environment irrespective of changing weather conditions outside these houses. This was done with the help of thermostat fitted heaters with blowers to keep temperatures in control during winter months. These houses are also equipped with air conditioners along with shade clothes on top of the butterfly and caterpillar houses to keep the temperatures at required level during summer months of the year. Humidity is controlled manually by spraying water in summer and in winter by keeping mild hot water. These measures helped in creating most favourable conditions to the butterflies throughout the year.

## Butterfly Breeding and Rearing Techniques

Butterflies chosen for captive breeding are –

1. Common mormon (*Priniceps polytes*)
2. Lime butterfly (*Priniceps demoleus*)
3. Plain tiger [*Danaus (Anosia) chrysippus*]
4. Common crow (*Euploea core*)
5. Psyche (*Leptosia nina*)
6. Common grass yellow (*Eurema hecabe*)

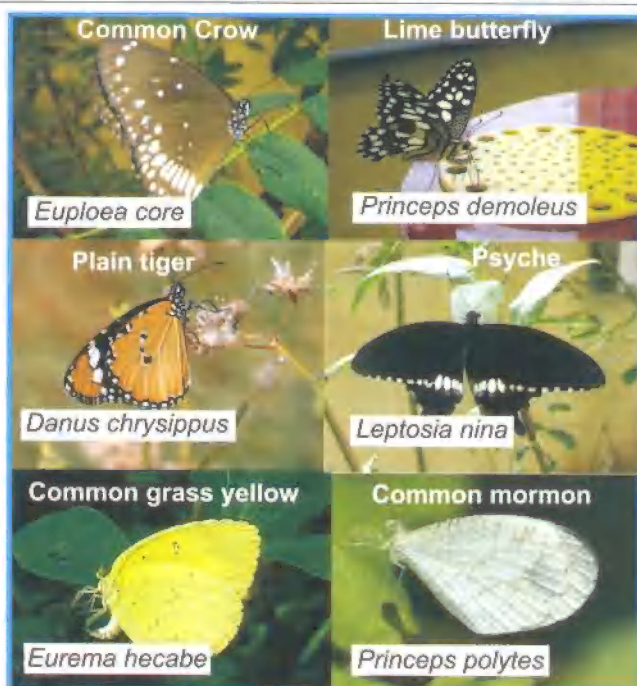


Fig. 3 Butterflies chosen for breeding at RSC, Guwahati

## Techniques Adopted in Breeding Butterflies

These are all common species, easy to rear and their host plants are easily available in nurseries. Male and female species of above butterflies were released inside the house. Host plants like citrus species for common mormon and lime butterflies, capparid species for psyche butterfly, cassia species for common grass yellow, calotropis species for plain tiger and ficus and nerium species for common crow butterflies were kept in the butterfly house to allow the butterflies to lay eggs.

Host plants with eggs were shifted from the butterfly house to nurseries where caterpillars hatched after 5-6 days depending on the species. Once caterpillars started feeding these leaves, defoliated host plants were replaced with new host plants with full foliage so that caterpillars get sufficient food throughout their growth period, till they become pupa. Just before the caterpillars reached pupa stage, these host plants were shifted to wooden cages so that caterpillars do not roam all over the room. Once the caterpillars transformed into pupa, they were removed gently from these boxes and placed in pupa boxes where they were allowed to develop into butterflies and hatch. This entire process of metamorphosis i.e. hatching from egg to formation of pupa takes about 3 weeks but it varies from species to species.

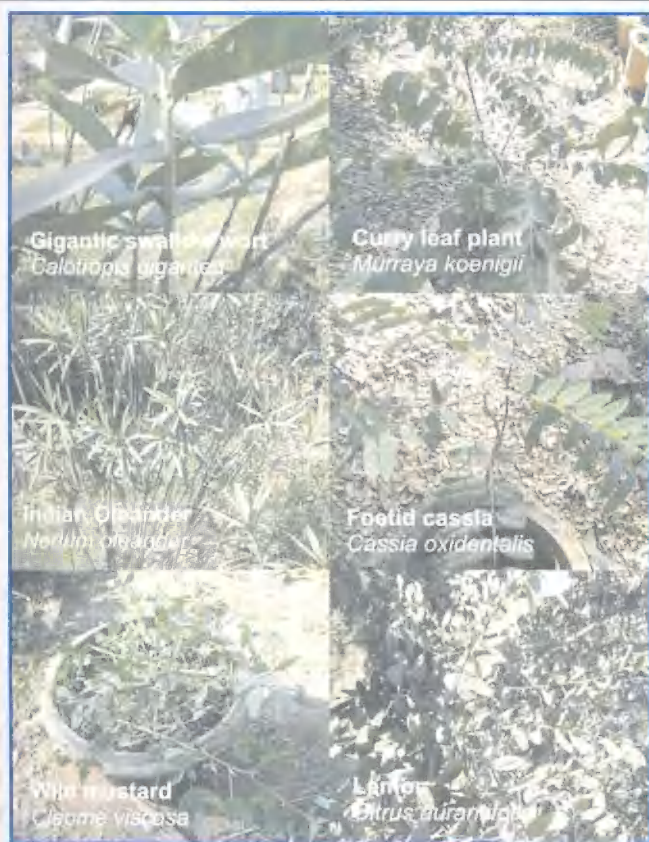


Fig. 4. Larval food plants



Fig. 5. Nectar plants

Handling techniques for hard species like common mormon, lime, plain tiger and common crow (strong species) are different from small and delicate species like psyche, common grass yellow. Species like common mormon, lime, plain tiger, blue tiger and common crow are relatively large in size, they are hardy in their body built and easy to handle where as species like common grass yellow and psyche are small in size and very delicate. Hard species caterpillars can be collected with our hands and can be reared in caterpillar boxes. Caterpillar boxes are stuffed with host plant leaves so that caterpillars get their food throughout their development.

Delicate species like common grass yellow and psyche should not be handled as far as practicable. They were allowed to grow and pupate on their host plants. Finally, when they were about to hatch, they were covered with a mosquito net. Butterflies were allowed to hatch on their host plants and released in the exhibition area by removing the net from the host plants. This has become possible only because host plants of these butterflies are relatively small and easy to handle. Picking of caterpillars and pupae may cause injury to them. Another method adopted in handling pupae of these butterflies was, cutting the branches where they have formed and hanging them with the help of crocodile clips in pupa boxes. Difficulty with this method is, while transferring butterflies from these boxes to exhibition area there is a chance of getting damaged due to bad handling. Pupae of common crow, plain tiger, common mormon and lime butterflies were collected gently from the host plants and kept in the pupa boxes. These boxes are equipped with thermocol strips with holes and crocodile clips, in which pupae were placed for hatching. Newly hatched butterflies were allowed in their pupa boxes till they dry their body and wings and blood is pumped in the wings. Handling them when they are wet may lead to crippling of their wings and body. From pupa to hatching of butterflies takes about 6-7 days. This again depends on the size of the butterflies.

## Role of Butterfly Gardens in Environmental Education and Ecological Conservation Programmes

A live butterfly garden in the Science Centre helps in many ways in imparting environmental education. With such facility, we can conduct the following activities in the Centre.

- Explain the entire life cycle of a butterfly which is also an insect and represents largest animal

group under the Phylum Arthropoda. Butterflies are liked by all age groups and they help in attracting visitors to the science centres. Various modifications undertaken by these small creatures to attain the form of a butterfly, e.g. eggs, different stages of caterpillar, moulting process, pupation and hatching into butterfly can be shown to the visitors. Also to explain habitats required for these creatures to the students and general masses.

- b) Butterflies are biological indicators of nature. Their presence in an area indicates the presence of their host and nectar plants, and also that the surrounding environment is clean and free from pollutants. We can create awareness among students from the young age.
- c) Regional Science Centre, Guwahati utilized the butterfly house in creating awareness among students to rear caterpillars till they become butterflies and release them in their suitable habitats. With these activities many students started joining hobby camps conducted by this Centre.
- d) Most importantly, role of butterflies in agriculture by way of pollination in plants and in food chain can be explained to museum/science centre visitors.
- e) We can create awareness among people regarding need for conservation of these creatures and their habitats in order to save them from reaching endangered list.
- f) We can also explain various biological control measures. Different species of caterpillars feeding on larval food plants, thereby controlling the growth of these plants. In the process along with larval food plant leaves, they are destroying other insect eggs like aphid eggs etc.

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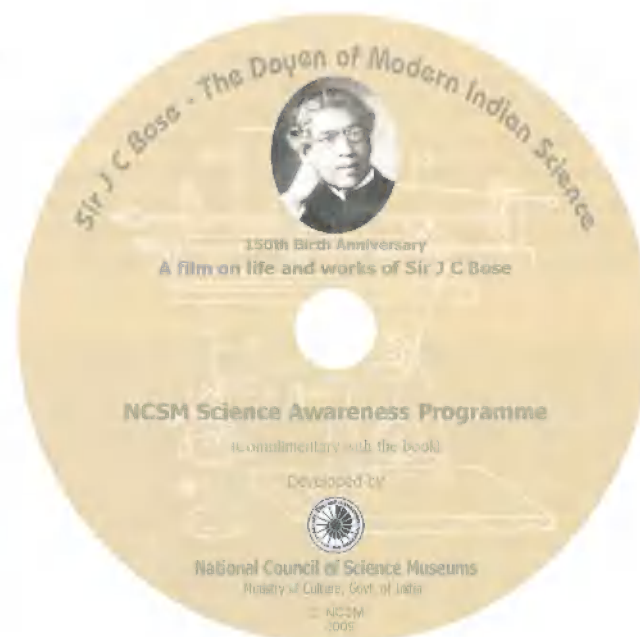
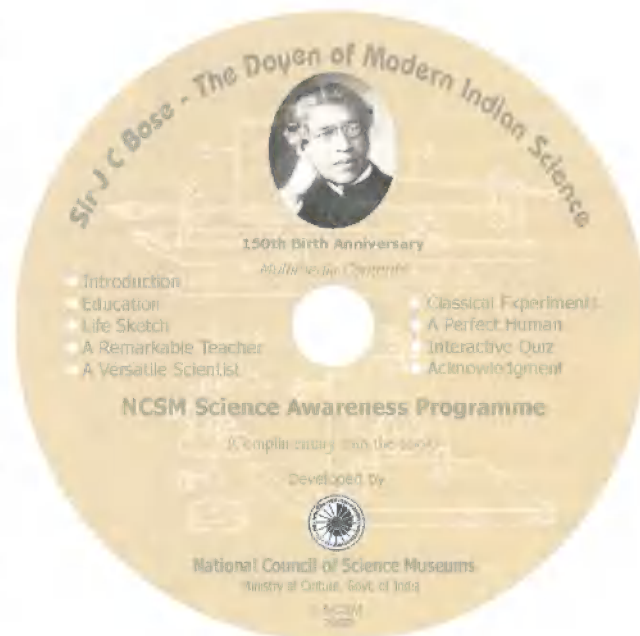
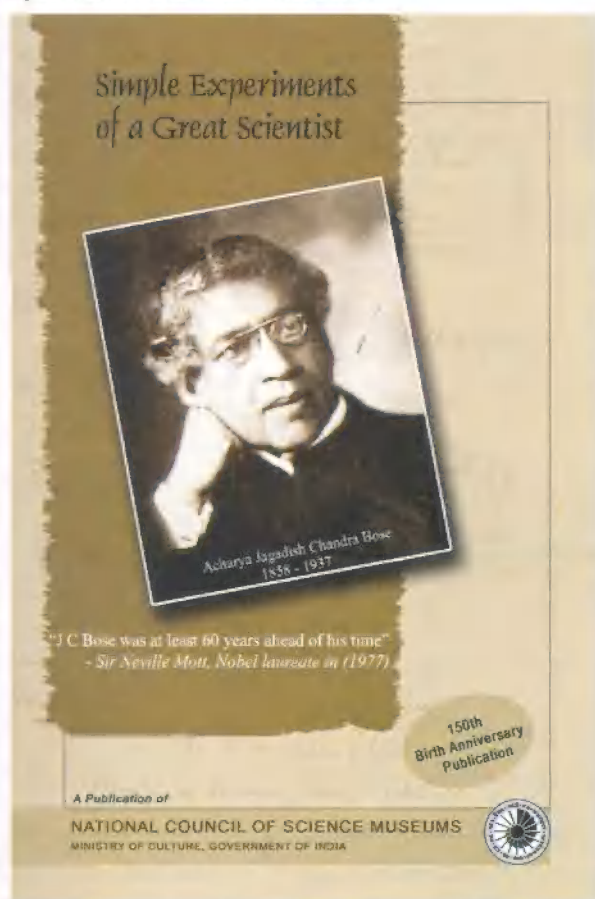
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## A Tribute to the Legendary Scientist Acharya Jagadis Chandra Bose

Kanchan Kumar Chowdhury

Acharya Jagadis Chandra Bose was a genius with multifaceted qualities. During his time, and afterwards too, he inspired Indians deeply with his startling inventions and fight against racism. His pioneering work in physics includes generation and reception of electromagnetic waves of millimetre wavelength (microwave), which received spontaneous recognition. On the other hand, in biological science he demonstrated that plants respond towards external stimuli like animals; but this novel findings received scarce and skeptic recognition. Nevertheless, when recognition came, he humbly submitted that he had only disseminated the knowledge known to the Indian sages for thousands of years. True to this spirit, Acharya Bose never commercialised his inventions, as he wanted to dedicate his inventions to the welfare of mankind.

Although much has been published on the life and works of Acharya J C Bose, the National Council of Science Museums (NCSM) has taken a new initiative to bring out the scientific as well humanistic qualities of this great scientist in an interactive manner through a book titled *Simple Experiments of a Great Scientist*, an interactive multimedia, and a movie 'Sir J C Bose – the Doyen of Modern Indian Science.'



The book is an attempt to bring the essence of the great scientific experiments of Acharya Bose to young students. The approach is to give an account of his simple and classical experiments rather than giving a chronological description of his life and work. The first section of the book contains a brief introduction of Acharya J C Bose followed by his contribution as a scientist and historical importance of his work. In the next section, ten important experiments of Acharya

Bose are described. Each experiment is arranged in different sections such as 'Objectives', 'Experimental procedure', 'Observation', and 'Scientific explanation'. At the end of each experiment, a section titled 'Experiment that you can do' is added where some new experimental ideas are given for the students that they can perform themselves. The last section highlights the relevance of Bose's research in present day context; a brief description of some of his brilliant works; a chronological description of his life; and a list of research publications and books written by him. The movie and the multimedia are complementary to the book.

The multimedia program on the life and works of Acharya J C Bose comprises the following sections:

- \* *Introduction*
- \* *Education*
- \* *Life sketch*
- \* *A remarkable teacher*
- \* *A versatile scientist*
- \* *Classical experiments*
- \* *A perfect human*
- \* *Interactive quiz*

In the 'Classical experiments' section, the working principles of some of the very simple and inexpensive equipment, largely designed and developed by Acharya Bose have been shown through animation. This section is also enriched by the inclusion of demonstration of his experiments by renowned scientists. In the 'Interactive quiz' section, the users can verify their knowledge about the works of Acharya J C Bose. The other sections of the multimedia are presented in the form of narratives with

some interesting stories associated with each. The multimedia has been developed in both, English and Hindi.

It is a common belief that Acharya Bose was the inventor of radio and that he had established the fact that plants have life. In the movie the story starts with these two basic questions that were asked to students as well as to common people. It is indeed an effort to enhance the true public perception about Acharya J C Bose. Today we can all access the benefits of technologies and witness the marvels of interdisciplinary fields. But how did it all start and had anybody in India perceived such a concept? This interesting question is addressed in the movie and It has been shown why Acharya J C Bose was 60 years ahead of his time, as remarked by Noveile Mott, a Nobel Prize winner in physics in 1977.

The vanishing border line between living and nonliving, the response phenomena in plants, and wireless communication all are the pillars of present day technologies. The birth of the transistor, the biggest revolution in 20<sup>th</sup> century, was predicted by Acharya Bose in his invention of detectors. These fantastic outcomes of his research have been shown in the movie. Acharya Bose had developed more than a hundred instruments and many of them are shown in the movie. The duration of the movie is 40 minutes. The movie has been made in English and Hindi.

It is hoped that this effort of NCSM will be a source of inspiration for young students and would help them to perform Acharya Bose's classic experiments, enhance their basic knowledge, and give them a joyful experience of doing science.



Dr. Kanchan Kumar Chowdhury, Curator, National Council of Science Museums (Headquarters), Kolkata.

## Lightning Wheel

Abdullah Mondal

Charge density tends to be very high on sharp points of a conductor<sup>1-5</sup> if it is connected to a high voltage source. The electric field strength immediately above a charged surface is proportional to the surface density of charge<sup>2</sup>. So electric field near the sharp points can attain a very high value. Since electrostatic pressure on a charged body increases with surface density of charge<sup>4</sup>, leakage of charge becomes more effective at sharp points.

Normally air does not conduct electricity. However, it contains a small number of charged particles produced by ionizing radiation<sup>2,6</sup>. Such a particle close to the charged conductor is accelerated by the electric field. If the field is very intense, it picks up enough speed and ionizes other air particles<sup>1</sup>. As a result, more ions are produced. The ions having similar charges to that of the charge on the conductor are strongly repelled by it. This constitutes an electric wind<sup>2,3</sup>, the action of which is used in lightning conductors<sup>5,6</sup>. The charge particles with opposite sign are attracted to the sharp points and neutralize its charge. So the conductor loses charge to the surrounding air<sup>2</sup>. The motion of the charged particles may constitute a discharge or leads to a lightning spark.

A working exhibit has been developed based on this principle. The exhibit comprises of a set of two similar wheels of 56 cm diameter each as shown in the schematic diagram in (fig.1). Each wheel comprises of

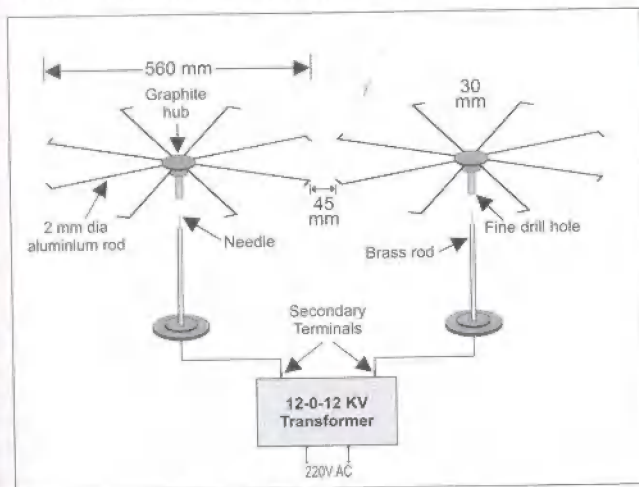


Fig. 1. Schematic diagram of the experimental set up

eight spokes, and is made of light weight material, aluminium. The ends of the spokes are bent at 90° and the tips are made sharp. The central hub that holds the

spokes is made of graphite. The choice of graphite is obvious, a conducting, light weight and lubricating material. It offers very less frictional resistance. A small hole is made at the bottom of the hub for pivoting. The graphite-hub supporting the wheel can rest on the tip of a fine needle; the other end of the needle is supported on a vertical stand. Accordingly, the wheels are quite free to rotate on a horizontal plane. Arrangement is made to vary the gap between the wheels. However, under this experimentation the gap is always maintained at 4.5 cm.

The wheels were connected to the secondary terminals of a 12-0-12 KV transformer under different experimental conditions. At first, only one wheel was connected to one of the terminals, leaving the other floating. The wheel was found to rotate when the device was switched on. Secondly, both the wheels were connected to one terminal leaving the other floating as in the first case. It was found that both the wheels rotate, but this time rotational speed was found to be less than the first case. Thirdly, the two wheels were connected to two separate terminals so that at any moment when one of them turned positive the other turned negative. This time interesting things happened. Both the wheels were seen to rotate with greater speed and at the same time they produced sparks within them. The sparks resembled intermittent lightning, tracing their zigzag paths in air (fig. 2) and generating intrinsic sound of its own kind.

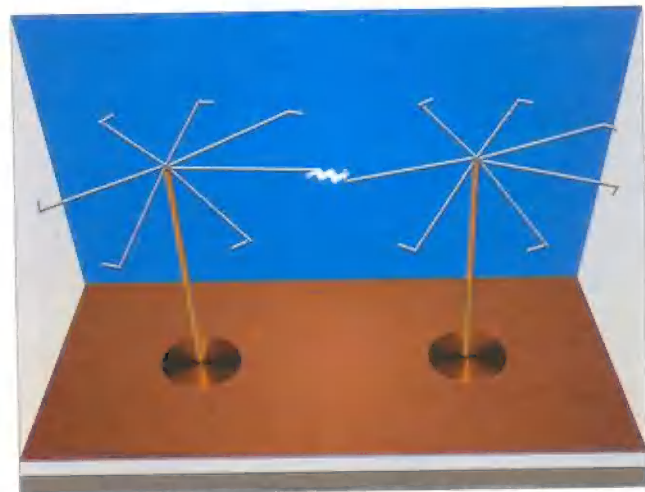


Fig. 2. A Lightning Spark

The variation of rotational speed in different cases may be analyzed in the light of accumulation of charges in the surrounding air. In the second case, when

both the wheels are connected to only one terminal, at any given time they either become positive or negative. The winds are therefore set up by same kind of ions and they repel each other. Consequently, for a short while, accumulation of charges take place in the gap between the wheels, hindering the winds therein to flow freely. Reaction force is therefore reduced to some extent. The wheels thus rotate slowly. In the last case the wheels are charged oppositely because they are connected to two opposite terminals of the transformer. The ions in the electric wind of one wheel are therefore attracted by the other. The wheels thus rotate faster because of the greater reaction force. Simultaneously, they produce spark within the gap.

To study the leakage of charges, current flowing through the device was measured under different conditions. It is to be mentioned that relative humidity while performing the experiment was sixty five percent. The primary voltage was kept at 220V. When only one wheel was connected to one terminal of the transformer, average primary current was found to be 2.32 mA. When both the wheels were connected to a single terminal, primary current was 2.46 mA. Current does not increase in that way though number of sharp points becomes double in this case. This shows that leakage of charges from the wheels takes place at a slower rate. On the other hand, when they were connected to two opposite terminals, primary current was found to be 2.80 mA. It agrees with the observable fact of increasing rotational speed of the wheels. This happens due to enhanced leakage of charges under this

condition. However, the current jumped to 7.0 mA or even more when sparks were created. They break intermittently due to increase in spark length since the gap between the spokes continuously goes on changing. The sparks resemble a lightning phenomenon. However, unlike normal spark discharges<sup>7</sup>, in most cases more than one spark were produced.

The demonstration is simple and the working principle is exciting in the way to understand electricity. Without using any expensive equipment like electrostatic generator or Tesla coil, rotary motion in a set of wheels with spectacular lightning effect can be generated by using an ordinary step-up transformer.

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## Communicating Multi-wavelength Astronomy through Exhibit

Manash Bagchi

### Abstract

Popular perception of astronomical observation is imposing on one to believe that universe is studied only through optical telescopes stationed in terrestrial observatories. Yet, a significant part of the astronomy observation is made in wavelengths spanning other parts of the Electromagnetic Spectrum. And the observation points are bound to be out in space for scanning in certain wavelengths. This expanded nature of astronomy observation was presented in an interactive exhibit *Seeing in different lights* in the exhibition *Messages from the Heaven* developed by National Science Centre, Delhi. The exhibit design was conceived through our interaction with the students attending astronomy workshops and they were consulted to conceive the user point-of-view of the possible exhibit addressing this topic.

### Genesis

'How do we know what is happening all the time in the universe?' we asked the students in the astronomy workshop. 'Observing through Telescopes' - was the unanimous answer. But, light becomes feeble at great distances; Inter-stellar clouds block visible light, earth's atmosphere do not permit all types of radiation to reach the ground, not all astronomical objects emit strong enough visible light. And to know the universe, in its completeness, we must overcome all these problems! Kids did not seem to have the appropriate comprehension of these complications.

We explained them with a scenario - suppose a person goes to a concert and he is so heavily impaired of hearing that he can only listen to sounds made in C-sharp. Can he enjoy the concert? Children seemed to realize his limitation. When all other persons will hear all the sounds from every instrument, the person with hearing impairment will never be able to hear the wholesome music. This analogy helped students in comprehending what one can miss in terms of observational astronomy if we were to restrict our studies solely on observation through optical telescopes.

The visible light - the light we see with our eyes - covers only a small portion of the vast electromagnetic spectrum which also includes gamma rays, X-rays, ultraviolet, infrared, microwaves, and radio waves (Fig. 1) with different types of radiation characterized by

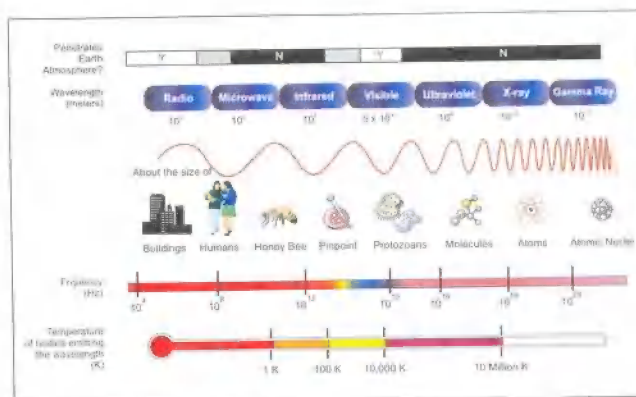


Fig. 1 Electromagnetic spectrum

their wavelength or frequency. Wavelength increases and frequency decreases from gamma rays to radio waves and all these waves travel at the speed of light. Objects radiate energy some of which is visible to our eyes while most of it is not. Even the radiation that is not visible to us has information of the objects' inner physical states. If we can read them properly, we know what is happening inside them.

For a complete picture of the Universe we need to see it all across the electromagnetic spectrum. Technological developments over the past seventy years have led to electronic detectors capable of seeing light that is invisible to human eyes. In addition, we can now place telescopes with special detectors on satellites and on high-flying airplanes and balloons which operate above the obscuring effects of Earth's atmosphere. A black cat in a dark room is missed out by our eyes while the same is seen through the Night Vision Camera with IR Sensor (Fig. 2). Likewise we



Fig. 2 Infrared view of a black cat in a dark room

miss out a lot of the universe if we were to see it only through the visible light. When we discussed these facts, students readily wanted to know how the universe will look in other lights, resulting in our designing the exhibit "Seeing in Different Lights" for the exhibition *Messages from the Heaven* to commemorate IYA 2009.

## Exhibit Design

Students nurture an idea that professional astronomy is done through only big-sized reflector and refractor telescopes kept on earth-based observatories. Though the positioning of Hubble Telescope in space was known to them, its purpose was not clear. This called for a means to instill, in them, an idea that astronomy is done throughout the EM spectrum and that every type of telescope cannot work from the earth-base because of the atmospheric shield around the earth. These ideas were too technical and an all encompassing design was elusive, till we zeroed on an interface shown in the Fig. 3. In juxtaposed graphics we presented what is the Electromagnetic Spectrum and how does atmospheric opacity vary with respect to wavelength of the spectrum. The EM spectrum graphic compared dimensions of known things with wavelengths of different types of EM waves differing only in their wavelength. The atmospheric opacity



Fig. 3 The exhibit – *Seeing in different lights* – from the exhibition *Messages from the Heaven*

graphic (Fig. 4) was intended to simplify the idea that while EM waves from different extraterrestrial sources are coming to us, different wavelengths are blocked at different heights. Two broad windows in the scheme were shown to represent that only EM waves in optical and short wavelength radio wave regions can reach earth surface. So, observations only in those ranges are possible from earth. But, for receiving UV, X-ray and Gamma ray signals, our respective telescopes have to be positioned outside the atmospheric cover. To further elucidate these points, we embedded translite images

of appropriate telescopes working in these ranges and coupled them with actuator switches so that pressing them one can see, in a central display, an audiovisual presentation showing the astronomical objects observed in that range of wavelength.

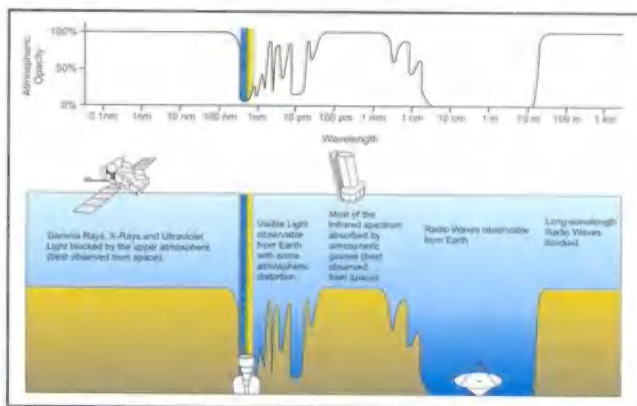


Fig. 4 Variation of atmospheric opacity with wavelength of EM Spectrum

The control circuitry is represented by the block diagram in Fig. 5. Telescope selection switches send signals to a microcontroller that selected and played appropriate media files through a video player. Depending on the telescope selected, the exhibit unfolded in steps, which are the objects that are particularly observed/monitored in that part of the spectrum and how do the commonly known objects look when they are seen through them.

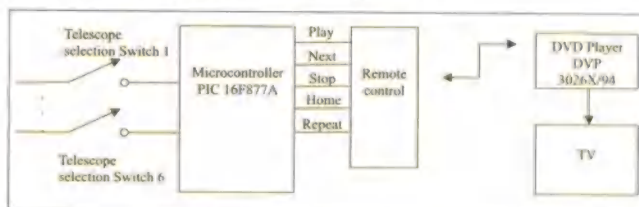


Fig. 5 Control Circuit Block Diagram for the exhibit *Seeing in Different lights*

## Content coverage

By interpretation of the multiwavelength observation of astronomical objects we guess the temperature, energy and type of the objects in a part of the universe. Multiwavelength studies give us information about the different layers in the atmospheres of planets and some of their moons. Observing the Sun in different parts of the spectrum allows us to study details in different layers of the solar atmosphere. Comets emit X-rays and why do they do so is still a mystery. Infrared observations have shown us that our solar system is filled with comet dust and that the giant planets Jupiter, Saturn, and Neptune not only reflect heat from the Sun, but create their own heat as well. Ultraviolet observations have led to the discovery

of auroras on both Jupiter and Saturn. We expected our student visitors to go excited about them and also to pursue these mechanisms at the research level when they are beyond their classrooms and ready for their career.

The X-ray image of the Sun shows us the structure of the hot corona – the outermost layer of the Sun. The brightest regions in the X-ray image are violent, high-temperature solar flares. The ultraviolet image shows additional regions of activity deeper in the Sun's atmosphere. In visible light we see sunspots on the Sun's surface. The infrared photo shows large, dark regions of cooler, denser gas where the infrared light is absorbed. The radio image shows us the middle layer of the Sun's atmosphere. In visible light we see sunspots on the Sun's surface – the regions of lesser temperature. All these help us to study the types of reactions going in the Sun, and in turn, they help us understand its course of evolution.

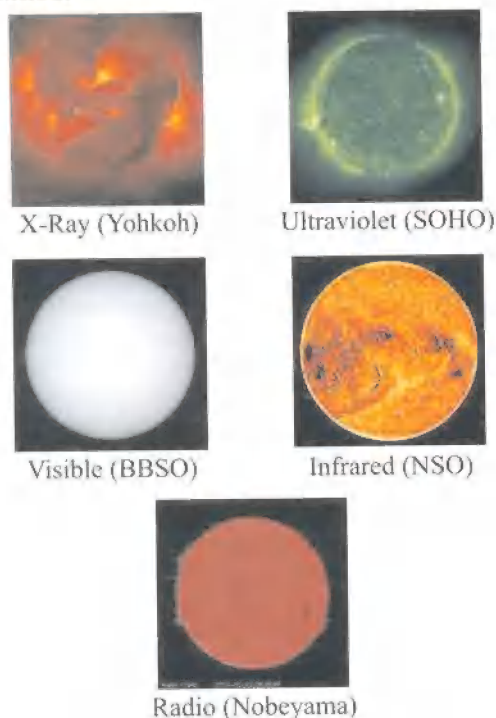


Fig. 6 Sun observed in different lights

Beyond the sun, within our galaxy, the infrared image shows areas which appear dark and empty in visible light. They reveal bright molecular clouds in which new stars are being formed. Infrared astronomy has revealed disks of material around other stars in which planets may be forming, wisps of warm dust throughout the galaxy, vast numbers of cooler stars, and the core of the Milky Way. X-rays tell us about the hot outer atmospheres of stars and the final phases of a star's life. When a star explodes, it ejects hot shells of gas which radiate strongly in X-rays. This makes the X-ray region of the spectrum a valuable place to learn

about supernovae, neutron stars, and black holes. X-ray observations have also led to the discovery of a black hole at the center of the Milky Way. Radio waves also bring us information about supernovae and neutron stars. In addition, radio observations are used to map the distribution of hydrogen gas in our galaxy and to find the signatures of interstellar molecules.

The X-ray photograph in the Orion region of the sky reveals Sun-like stars, white dwarf stars, neutron stars, and supernova remnants in our own Galaxy, and (in the background) nearby galaxies, clusters of galaxies, and distant quasars. The ultraviolet image is a close-up view of the belt/sword region of Orion, including the famous Orion Nebula, and is dominated by emission from hot, young stars.

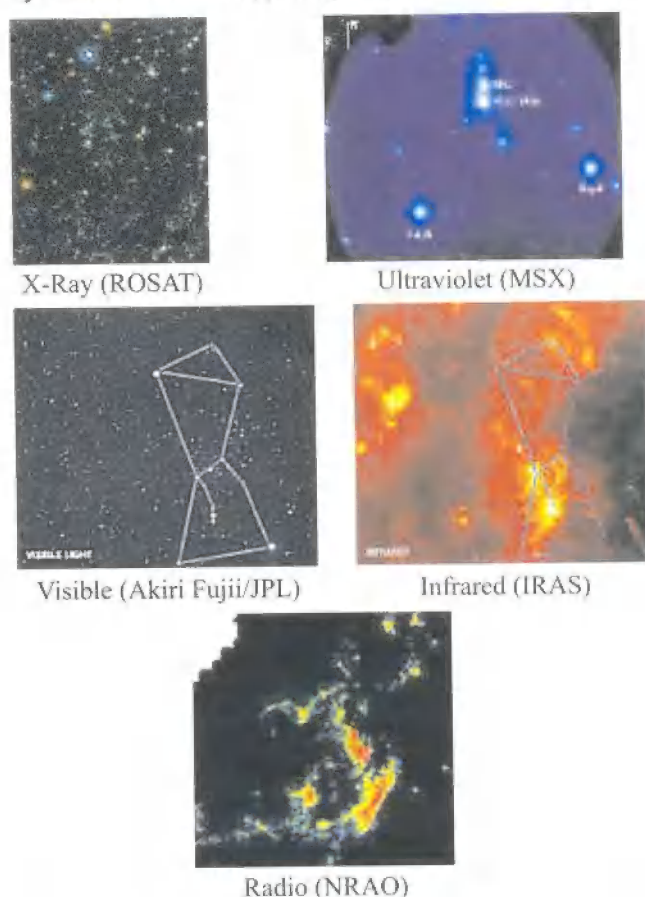
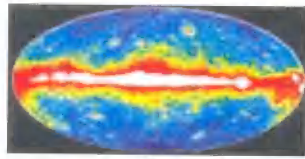


Fig. 7 The Orion region of sky in different wavelength

The visible light image shows stars of all ages and temperatures. In the infrared, our view of Orion is dominated by emission from clouds of dust and gas, the materials from which new stars will be born. The radio image maps the distribution of hydrogen molecules in the interstellar medium, with red showing the areas of highest concentration.

All-sky maps portray the entire Milky Way Galaxy (Fig. 8). They are painstakingly formed by taking images of the entire celestial sphere, and then unwrapping and stretching them to fit onto a

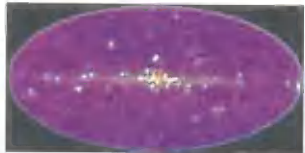
two-dimensional surface. The Galactic Center is at the center of each image, with the plane of the Galaxy stretching from left to right like the equator on Earth.



Gamma-Ray >100MeV  
(CGRO, NASA)



Gamma-Ray (N. Gehrels et al.  
GSFC, EGRET, NASA)



X-Ray 2-10keV (HEAO-1,  
NASA)



X-Ray 0.25, 0.75, 1.5 keV (S.  
GSFC, ROSAT, NASA)



Ultraviolet (J. Bonnell et al.  
(GSFC), NASA)



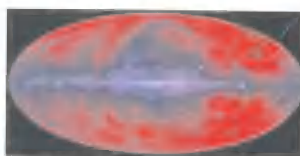
Visible (Axel Mellinger)



Infrared (DIRBE Team,  
COBE, NASA)



Radio 1420MHz (J. Dickey et al.  
UMn. NRAO SkyView)



Radio 408MHz ©. Haslam  
et al., MPIfR, SkyView)

Fig. 8 Multiwavelength Milky Way

Each image is dominated by the emission from the disk and central bulge of the Milky Way, where most of the contents of our galaxy are contained.

Gamma-rays have more than a million times the energy of visible light. So, the first gamma range picture shows us areas where high-energy cosmic rays collide with hydrogen in interstellar clouds. The next gamma-ray image highlights the most intense gamma-ray sources. Some of these bright areas have been identified as black holes, neutron stars and quasars. Most of these however, remain a mystery and have not yet been identified with complete certainty.

X-rays are about 1,000 times more energetic than visible light and the first X-ray image shows the brightest X-ray emitters in the Milky Way. These high-energy X-rays are produced in high-temperature environments. They are identified as white dwarfs, black holes, neutron stars, pulsars, supernova remnants, active galaxies, flare stars, and high energy binary star systems. The next X-ray image maps hot gas and show large, looping structures. The gas and dust clouds in the plane of the Milky Way block X-rays and cause this area to appear dark.

The ultraviolet image reveal stars, quasars, external galaxies, supernovae and nebulae. Visible light provides us with a view of the overall distribution of stars. The dark patches along the galactic plane are regions of dense gas and dust which block visible light. In the infrared we see glowing dust which is heated by starlight as well as regions of intense star formation (brightest areas). The remarkable S-shaped blue sash is the structure of zodiacal dust bands which are small pieces of rock and dust orbiting between the Sun and Jupiter. The galactic plane no longer shows dark patches in the infrared. This is because infrared light can penetrate gas and dust clouds causing this region to glow in the infrared.

The higher energy radio image maps the distribution of the hydrogen gas which fills our galaxy. No stars are seen in this image. All we see are vast, diffuse clouds of hydrogen – the most abundant element in the Universe. The next radio view of the sky shows areas where synchrotron radiation (radiation which occurs when charged particles are accelerated in a curved path or orbit), and hence electrons and magnetic fields, are dominant. This image also shows the location of pulsars and supernova remnants.

Beyond our Milky Way galaxy, multiwavelength astronomy unlocks a treasure of information. Visible light images show us the detailed structure of various types of galaxies, while radio images show huge jets and lobes of material ejected from galactic cores. X-rays are used to detect the signature of black holes in the centers of galaxies – the extremely hot material being pulled into a black hole at tremendous speeds. Infrared light has been used to discover thousands of galaxies which are undergoing intense star formation. Radio studies have detected the radiation left over by the Big Bang.

A multiwavelength look at the Whirlpool Galaxy (Messier 51), 37 million light years from Earth, reveals a face-on spiral galaxy gravitationally interacting with a smaller companion galaxy.

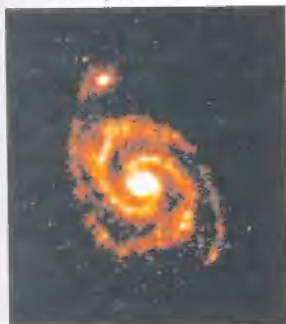
The X-ray image highlights the energetic central regions of the two interacting galaxies. Much of the diffuse glow is from multi-million degree gas. Many of



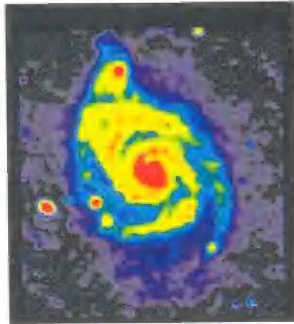
X-Ray (Chandra)



Visible (T. &amp; D. Hallas)



Infrared (ISO)



Radio (VLA)

Fig. 9 Whirlpool Galaxy in different lights

the point-like sources in the x-ray image are black holes and neutron stars in binary star systems. Visible light clearly reveals the sweeping spiral arms which include patchy knots of star formation. The companion galaxy, classified as an irregular galaxy, lacks the well-defined structure of a spiral galaxy and appears "attached" to the end of a spiral arm in the "Whirlpool Galaxy". Infrared is well-suited to studying star formation and tracing dust in spiral galaxies. The infrared image not only shows the galaxy cores and spiral arms, but nicely illustrates the knots of star formation occurring in the arms. The spiral arms extending from the galaxy center and the companion galaxy are clearly seen at radio wavelengths. A modest-sized red blob appears to be connected to the end of the southern spiral arm, located about the 8 o'clock position. This is interpreted as a probable background quasar.

## Conclusion

The information discussed above was presented to the visitor in the exhibit in an interactive way with a message that rapid advances in technology have made

the future of multiwavelength astronomy extremely bright. In the coming years and decades, we will continue to hear about many new discoveries being made across the spectrum. So the exhibit *Seeing in Different Lights* seemed to address an important area of cutting-edge astronomy. During one and half month of the exhibition at the National Science Centre, from our interaction with the visitors to the exhibition, it transpired that the objects observed in different wavelength gained good popularity and the fact that most distant objects like Pulsars and the farthest objects observed like the Gamma Ray Bursts (GRBs) can only be observed by high frequency region of the EM spectrum were established well with the visitors. Students showed great interest in the interpretations of the multiwavelength views of the Milky Way galaxy.

## Exhibit collaborators

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## Geomagnetic Studies in the 19<sup>th</sup> Century British India

Jayanta Sthanapati

### Introduction

Geomagnetism, formerly called terrestrial magnetism, is the branch of science that deals with the earth's magnetic field observed on its surface, within it and extending upward to the magnetospheric boundary. Presence of earth's magnetic field was known to the Chinese about 4000 years ago. They, however, took help from earth's magnetic field for navigation about 1000 years ago, only after inventing magnetic compass<sup>1</sup>.

The direction and strength of earth's magnetic field can be measured at its surface. It has several components, such as total intensity, horizontal intensity, vertical intensity, declination and inclination. Horizontal Intensity and Vertical Intensity are respectively horizontal and vertical components of total magnetic intensity of earth's magnetic field. Magnetic Declination is the difference between the True Meridians and the Magnetic Meridians. This difference reflects the tilt of the earth's magnetic field with respect to its axis of rotation. Since the magnetic poles and axis of rotation do not exactly coincide, compass needles do not indicate true North at most sites in the northern hemisphere, or true South at most sites in the southern hemisphere. While magnetic declination was determined in China about 1000 years ago, in Europe the concept of declination was known in early fifteenth century. The first precise measurement of declination was made by George Hartman (1489-1564), a German Astronomer in 1510 in Rome. Magnetic Inclination (dip) is the angle that the geomagnetic field is tilted with respect to the surface of the Earth. Magnetic inclination varies from 90° (perpendicular to the surface) at the magnetic poles to 0° (parallel to the surface) at the magnetic equator. Magnetic dip was first described by Robert Norman, a magnetic compass maker in London in 1581. There are three ways by which temporal variations of Earth's magnetic field occur and in turn affect exploration magnetic surveys to different extent. Secular Variations are long-term variations of Earth's magnetic field that occur slowly over a period of few years. Diurnal Variations occur over the course of a day. Magnetic Storms are magnetic activities associated with enhanced sunspot activities. During magnetic storms, earth's magnetic field becomes irregular<sup>2</sup>.

### The European Scene : From Gilbert to Gauss

Systematic work on geomagnetism began with the publication of William Gilbert's *De Magnete, Magneticisque Corporibus, et de Magno Magnete Tellure* (On the Magnet and Magnetic Bodies, and on the Great Magnet the Earth) in 1600. William Gilbert (1544-1603) was an English physician and natural philosopher. He conducted many experiments with small magnetic needles and a small spherical loadstone (his model earth) called the *terrella*. From experimental results, he concluded that the Earth itself was a giant loadstone.

Rene' Descartes (1596-1650), a French philosopher, mathematician and physicist gave the first illustration of a magnetic field in his book *Principia Philosophiae* (Principles of Philosophy) in 1644. He believed that the earth's magnetic field was caused due to streams of corkscrew shaped tiny helical particles, which circulated through parallel threaded pores in the magnet. They entered the magnet through the South pole and came out from the North pole. This theory remained in force until the early nineteenth century. Edmond Halley (1656-1742), an English astronomer, geophysicist, meteorologist, physicist and mathematician, was a pioneer of global magnetic survey. In 1683, he proposed that the earth consisted of an inner sphere and an outer shell, both rotated at different speeds and had independent north and south poles. He opined that due to interactions between these four poles, variation in declination and dip occurred. Between 1698 and 1700, Halley sailed the Atlantic to measure variations in declination and charted them on a map. In 1800, French physicist Charles Augustin Coulomb (1736-1806) and French mathematician Simon-Denis Poisson (1781-1840) assumed distance forces resulting from fluids locked in magnetic substances.

However, during 19<sup>th</sup> century, German naturalist and explorer, Alexander von Humboldt (1769-1859), Norwegian geophysicist, Christopher Hansteen (1784-1873) and German mathematician Carl Friedrich Gauss (1777-1855) formulated relationship between data, theory and mathematical analysis in studies in terrestrial magnetism. In 1805, Humboldt reported that magnetic intensity varied across the earth's surface. To plot these variations, he encouraged the establishments of a network of magnetic observatories. In 1834, Gottingen Magnetic Union suggested recording of simultaneous magnetic observations at 50 stations, including six in Asia. Christopher Hansteen travelled to Siberia around 1830

for geomagnetic investigation. The expedition brought fresh ideas and the evidence to geomagnetic studies. In 1830s, Gauss and Wilhelm Weber (1804–1891) did extensive magnetic measurements and launched *Magnetische Verein* (magnetic union) to establish a network of magnetic observatories worldwide. In 1838, Gauss opined that the Earth's magnetic source is at or very near its centre<sup>2</sup>. With such back drop, geomagnetic studies commenced in India.

### *The Indian Scene : From Taylor to Moos*

While articles on geomagnetic studies in the 19<sup>th</sup> century Europe and America are available<sup>3,4</sup>, only a very brief report exists on such studies in India during the 19<sup>th</sup> century<sup>5</sup>. From an exhaustive survey of literature on studies in magnetism in India between 1850 and 1980<sup>6</sup>, it transpired that out of 653 research papers on geomagnetism, published up to 1980, 35 reports were on studies in geomagnetism in British India, covering three major areas – Earth's magnetic field, geomagnetic variations and magnetic exploration. These studies were carried out primarily by nine European and an Indian researcher.

The first modern astronomical observatory in India was established at Madras (now Chennai) in 1792<sup>7</sup>, by the East India Company. Thomas Glanville Taylor (1804–1848) of Royal Greenwich Observatory, London headed Madras Observatory, during 1830–1848, as an Astronomer of the East India Company. A survey of published works on magnetic studies in India revealed<sup>8</sup> that Taylor was the first researcher in India to publish data on geomagnetic studies<sup>9</sup>. In his short paper he wrote, “Notwithstanding the value which has of late years been attached to observations of the Magnetic Dip and Intensity, I may, I believe, safely state, that the whole of British India has failed to put on record a single good set of experiments to this end”. He made observations of the magnetic dip and intensity at the Madras Observatory situated in Long. 5h. 21m. 7s.8 East of Greenwich, and Lat. 13° 4'4".8N. on the 26<sup>th</sup> April 1837. His observation showed that mean magnetic dip was 6° 52' 30", quite different from 5° 15' N which was recorded at Madras by Abercrombie (unpublished result) in 1775. Taylor thus concluded that the magnetic dip was on the increase at the rate of 1'34" in a year. Taylor left Madras on 23<sup>rd</sup> July 1837 to meet John Caldecott (1801–1849), an Englishman, who later became Director of Travancore Observatory at Trivandrum (now Thiruvananthapuram). Caldecott came to India in 1821 from England and was staying in Bombay (now Mumbai). In 1831, he was appointed Commercial Agent and Master Attendant at Alleppey as an employee of the Travancore Government in Southern India. At his bungalow at Alwaye, about 13 km NE of Cochin, he built an observatory with his portable astronomical instruments. The Travancore Observatory was founded by Raja Rama Vurma

(Sri Swathi Tirumal) in 1837. Caldecott started astronomical observations from the observatory in the same year. Caldecott and Taylor made joint geomagnetic surveys at Negapatam, Manaragoody, Sheally, Pondicherry, Poothocottah, Munanamelegoody, Kalenemary, Calicut, Penaney, Chetwaye, Bolghatty, Allepee and Trivandrum between 7 August and 20 November 1837<sup>10</sup>, but the results were not published in any scientific journal. Taylor, however, was more interested in astronomical observations. While in Madras between 1831 and 1842, he measured the position of more than 11,000 stars and published his observations in 5 volumes. Primarily for this contribution, Taylor was elected a Fellow of the Royal Society of London in 1842.

John Caldecott, on the other hand, while in London in 1838, came to know about the plan of British Government to set up a worldwide network of magnetic observatories. He arranged to buy a set of magnetic instruments from Grubb of Dublin to set up a magnetic observatory at Trivandrum. Raja of Travancore, Swathi Tirumal took keen interest in introduction of European scientific ideas in his estate and provided necessary funds to set up magnetic and meteorological observatory at Trivandrum in 1841. Unfortunately results of the observations of Caldecott were never published. In 1840, John Caldecott was elected a Fellow of Royal Astronomical Society of London. With an aim to carry out magnetic survey of India, Captain H.A.D. Frasar of Survey of India visited Europe in 1841 for acquiring preliminary knowledge on magnetic surveys and also to identify necessary instruments. During 1841–1845 Simla Observatory recorded magnetic data. It, however, discontinued measurements from 1846<sup>11</sup>.

John Allan Broun (1817–1879), a Scottish meteorologist made significant contribution in the field of geomagnetic studies when he was Director of the Trivandrum Observatory during 1852–1865. Broun had previous experience of working as Director of the magnetic observatory at Makerstoun in Scotland from 1842 to 1849. He believed that the Earth loses or gains magnetic intensity not locally, but as a whole and also found that solar activity caused magnetic disturbances. His research communications from Trivandrum Observatory described studies of mean magnetic declination, horizontal force of the Earth's magnetic field, diurnal variation of magnetic declination etc<sup>12</sup>. He was elected a Fellow of the Royal Society of London in 1853.

Henry Piddington (1797–1858) an English scientist, an official of East India Company and President of Marine Courts of Calcutta, while conducting magnetic studies at Saugor in Bundelkhand in 1849 noticed a very remarkable deviation of the reading of a prismatic surveying compass. He concluded that presence of a highly magnetic diorite ore in that locality was responsible for such an unexpected result. In an elaborate article, Piddington, in 1851, gave an account of studies on variation of rate of chronometers installed in ships due to terrestrial magnetism<sup>13</sup>. He wrote many research papers in diverse

fields, like mineralogy and meteorology, in the Journal of the Asiatic Society of Bengal.

The East India Company, on the recommendation of German naturalist and explorer Alexander von Humboldt, commissioned three German brothers Hermann Schlagintweit (1826-1882), Adolphe Schlagintweit (1829-1857) and Robert Schlagintweit (1833-1885) to carry out geomagnetic survey in India. Schlagintweit brothers were scientific explorers and great collectors of natural zoological, botanical and geological specimens<sup>14</sup>. They arrived in Bombay on 26<sup>th</sup> October 1854 and for the next three years travelled in various parts of the country, sometimes in company and sometimes separately. Hermann made magnetic observations at Sikkim, the Khosia Hills and Assam between April and December 1855 which included studies of magnetic dip and vertical force of Earth's magnetism. Between January and May 1856, Hermann made magnetic observations at Nurigoon in Bhutan, at Teipur, Dibroogarh and Gowhatty in Assam, at Dacca and Khoolna in East Bengal, at Benaras, Lucknow, Agra and Meerut in Uttar Pradesh and also at Calcutta. He measured magnetic dip and declination at these places. Robert conducted magnetic surveys at Shapore, Mooltan, Shikarpore, Sehwan, Kurrachi and Bhooj between December 1856 and March 1857. Adolphe Schlagintweit carried out magnetic studies at Agra, Saugaor, Dumoh, Jubbulpore, Nagri (south of Nagpore), Rajamundry, Pondicherry, Ootacamund and Bangalore between November 1855 and April 1856. During the same period, Robert carried out magnetic and meteorological studies at Jubbulpore, Umerkuntuk Hills, Rajmeergurh Hill, Nahun and Simla. Robert and Adolphe jointly conducted magnetic survey from April to October 1855 at Benaras, Nynsee Tal, Badrinath, Milum, Mana, Nelong, Ussila and Mussoorie. Together with the magnetic surveys, Schlagintweit brothers always made meticulous observation of temperature, moisture of the atmosphere, direction of wind etc. at every site<sup>15</sup>. After completion of their assignment, Hermann and Robert returned to Europe in early 1857. Adolphe remained to prosecute his explorations in Central Asia, but was put to death by the Amir of Kashgar in China in August 1857. Hermann and Robert published a four volume report titled 'Results of Scientific Mission to India and High Asia' between 1860 and 1866<sup>16</sup>.

Colaba Observatory, located on the island of Colaba near Bombay, was established in 1826 by the East India Company for astronomical observations and time-keeping purposes to provide necessary information to ships using Bombay as a port. Magnetic and meteorological studies were started at the observatory in 1841. Arthur Bedford Orlebar, a Professor of Astronomy at Elphinstone College, Bombay conducted studies in geomagnetism at the observatory intermittently between 1841 and 1845<sup>17</sup>. From 1846, when the observatory was properly equipped, it started regular magnetic measurements. Charles Chambers was appointed as the first full-

time Superintendent of Colaba Observatory in 1865. He equipped the observatory with autographic instruments for continuous recording of magnetic and meteorological observations. Between 1869 and 1893, he contributed eleven papers<sup>18</sup> on terrestrial magnetism. He investigated the solar variations of magnetic declination at Bombay, absolute direction and intensity of Earth's magnetic force and its secular and annual variations, secular variations of magnetic dip at Bombay during the years 1867-1893, etc. He was a Fellow of the Royal Society of London.

After the demise of Charles Chambers in 1896, Dr. Nanabhai Ardesher Framji Moos (1859-1936), a Doctor of Science of Edinburgh University, was appointed as the Director of Colaba Observatory. He was the first Indian to hold this position. He continued research in geomagnetism for nearly 24 years. In 1896, he gave an account of his predecessors in a publication titled "Fifty years of magnetic and meteorological observations at Bombay". Moos had studied the patterns of hourly variations of declination and horizontal and vertical forces on selected quiet days for the periods 1894-97, 1898-99, 1900-1901 and 1901-1905. His most important publication was on "Colaba magnetic observations : 1846-1905" in two parts, published by Government Observatory, Bombay in 1910. While the first part of the report described the magnetic observations and instruments used, the second part presented magnetic phenomenon and discussion on the observations<sup>19</sup>. He was a Fellow of the Royal Society of Edinburgh. In 1900, authorities of Colaba magnetic observatory came to know that electrical traction would be introduced in the city of Bombay soon, which might disturb magnetic observations. The observatory was shifted to a new location at Alibag, about 31 km south-east of Bombay. Since 1904 the Alibag Magnetic Observatory has provided uninterrupted record of geomagnetic observation.

Geomagnetic studies and surveys were of great importance in 19<sup>th</sup> and 20<sup>th</sup> Century British India and also in independent India. The origins of Earth's magnetic field, however, remains a long-standing issue and we do not have any scope to discuss on that topic in this article.

## **Acknowledgment**

The author is thankful to Dr Mitali Chatterjee, Librarian of The Asiatic Society, Kolkata for providing support in searching old literature on geomagnetic studies in India and to Dr. Supriya Mondal, Reader, Dept. of Geological Sciences, Jadavpur University for helpful discussion during preparation of draft manuscript of the present article.

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January 2010

Volume 1

Number 1

*Published by National Council of Science Museums*

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